The LARP Collimation Program

1 June 2005

LARP DOE Review-Fermilab

Tom Markiewicz
SLAC

LHC Collimation Requirements

LHC Beam Parameters for nominal L=1E34cm^{-2}s^{-1}:

- 2808 bunches, 1.15E11 p/bunch, 7 TeV $\rightarrow$ 350 MJ
- Δt=25ns, σ~200μm (collisions)

System Design Requirement: Protect against quenches as beam is lost

- Design shielding for expected <τ>~30hr or 3E9 p/s or 3.4kW
- Design collimator cooling for τ = 1 hour or 8E10 p/s or 90kW
- Plan for occasional bursts of τ = 12 min or 4E11 p/s or 450kW
  - abort if lasts > 10 sec

Collimation system inefficiency:

- Inefficiency · Max Loss Rate < Quench Loss Rate
- dQ/dV ~ 1.5mW/gm in SC coil causes quench
- Estimate inefficiency of collimation system via SIXTRACK program
- Determine minimum required inefficiency via FLUKA/MARS
  - 8E6 p/s on TC will quench Q3 in triplet $\rightarrow$ 2E-5 inefficiency @ 4E11 p/s loss

The LHC Collimation System

Betatron Collimation in IR7

- 3 short (20cm) “Primary” collimators (H,V,S) at 6σ
- 11 long (1m) “Secondary” Collimators (various angles) at 7σ

Momentum Collimation in IR3

- 4 long (1m) “Secondary” collimators

Other

- 1m H&V Copper Tertiary Collimators at Experimental IRs at 8.4σ
- 1m Cu or W Absorbers at 10σ
- Warm Magnets, tunnel and shielding absorb remainder of lost beam energy

Accident Scenario

When beam abort system fires asynchronously with respect to abort gap (armed HV trips accidentally) **8 full intensity bunches** will impact collimator jaws

Non-Accident Engineering Challenge

- The first long secondary collimator downstream of the primary system must absorb much more energy than any other secondary in the system since 80-85% of list particles interact inelastically in the 6σ primaries
- The deformation specification of the collimator jaw is set at 25μm in order to maintain system efficiency

Phase I and Phase II Collimation

Phase I: Use Carbon-Carbon composite as jaw material

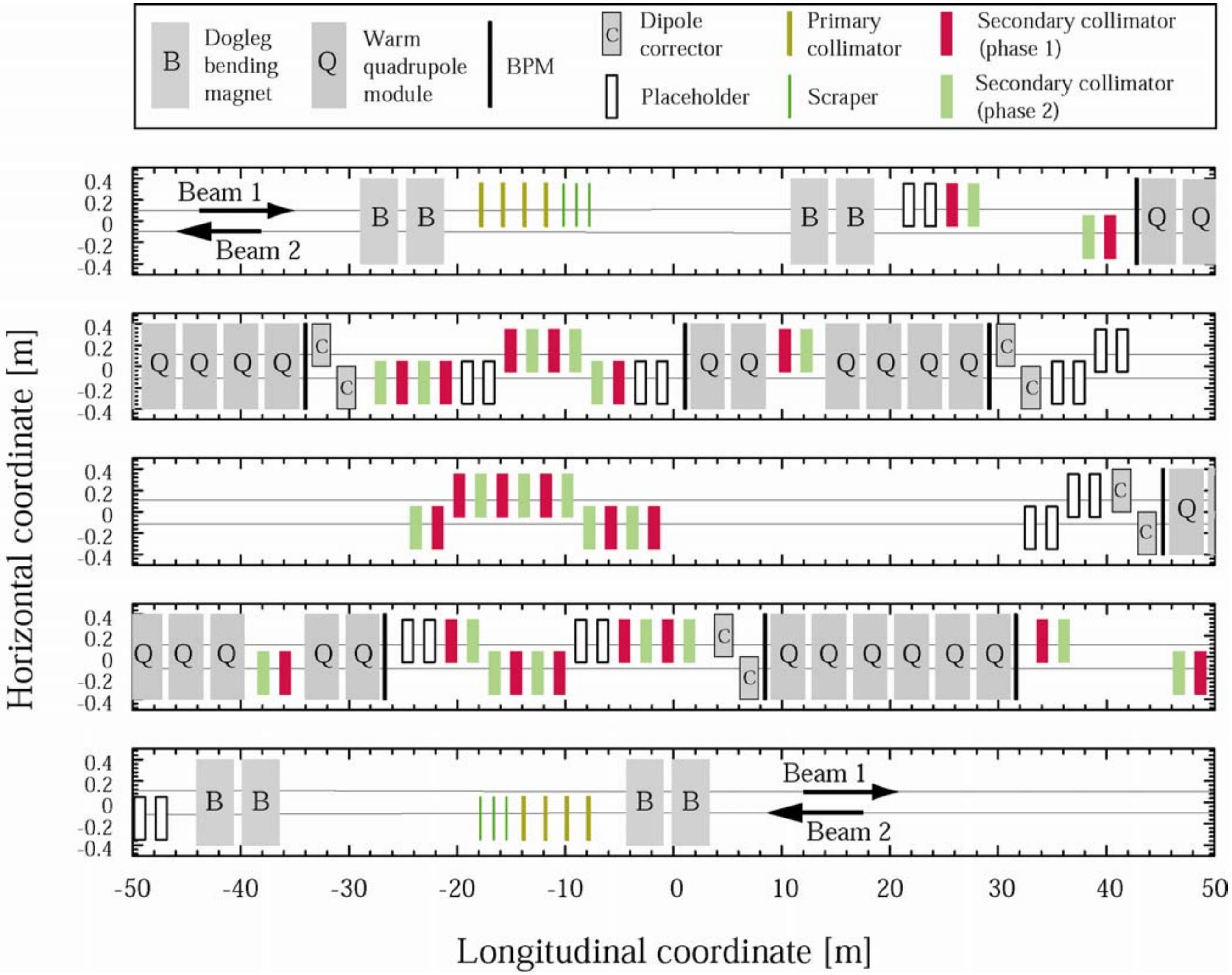
- 20cm/1m Carbon undamaged in Asynchronous Beam Abort
- Low energy absorption of secondary debris eases cooling & tolerances
  - 6-7 kW in first 1m C secondary behind of primaries when dE/dt=90 kW
    - 10 sec 450 kW load handled as a transient
- Low, but adequate collimation efficiency to protect against quenches at lower *L* expected at startup
- High, but adequate machine impedance for stable operation at low *L* expected at startup

Phase II: Metal collimators into vacant slots behind each Phase I secondary

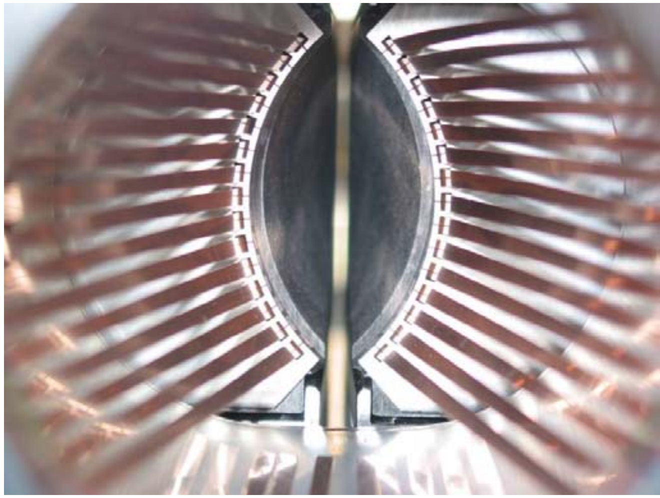
- Good impedance and efficiency allowing LHC to reach design L= 1E34
  - After stable store open Carbon jaws and close Metal jaws
- Jaw will be damaged: what to do?
- More energy from primaries will be absorbed: cooling & deformation
  - only pertains to one unlucky collimator per beam!

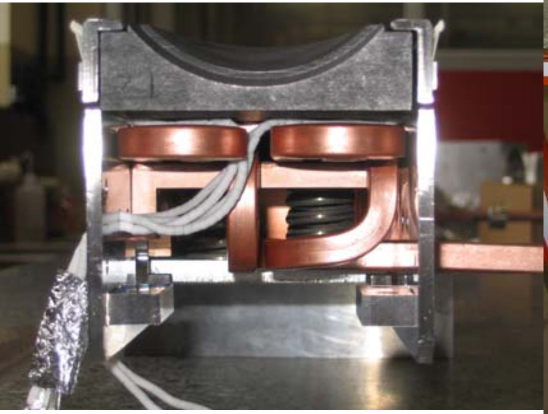
IR7 Collimator Layout

11 Carbon Phase I and 11 Metal Phase II Secondary Collimators per beam in IR7

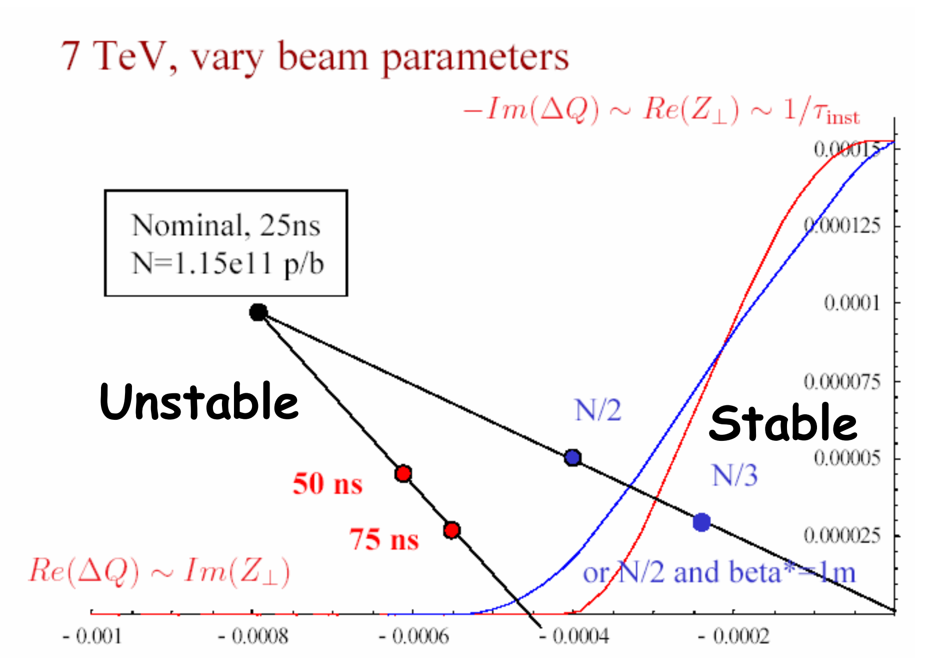


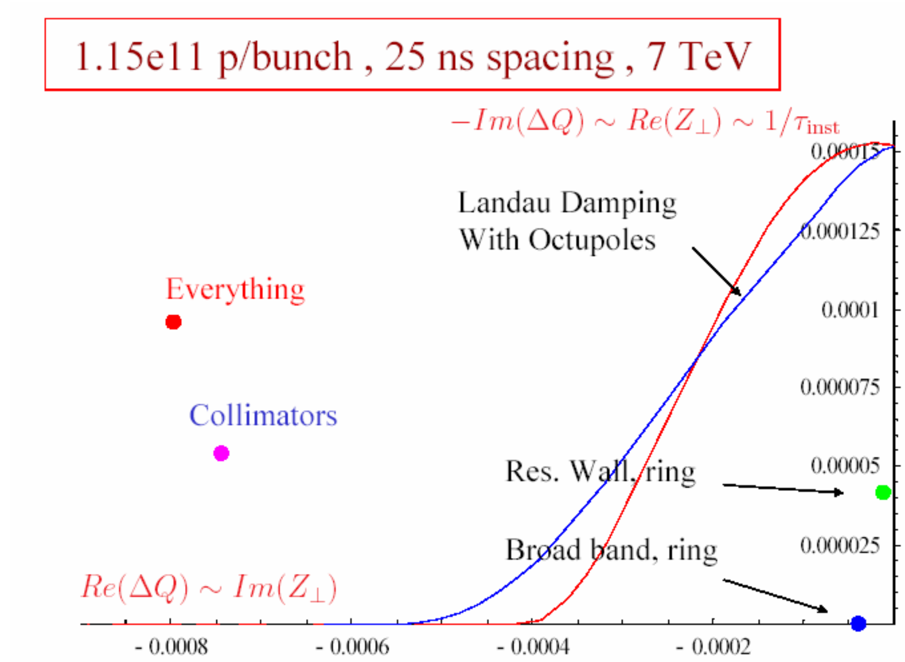
LHC Phase I 25x80mm^2 Carbon/Carbon Secondary Collimators w/ 7kW cooling Prototypes Made & Tested Full Order Placed





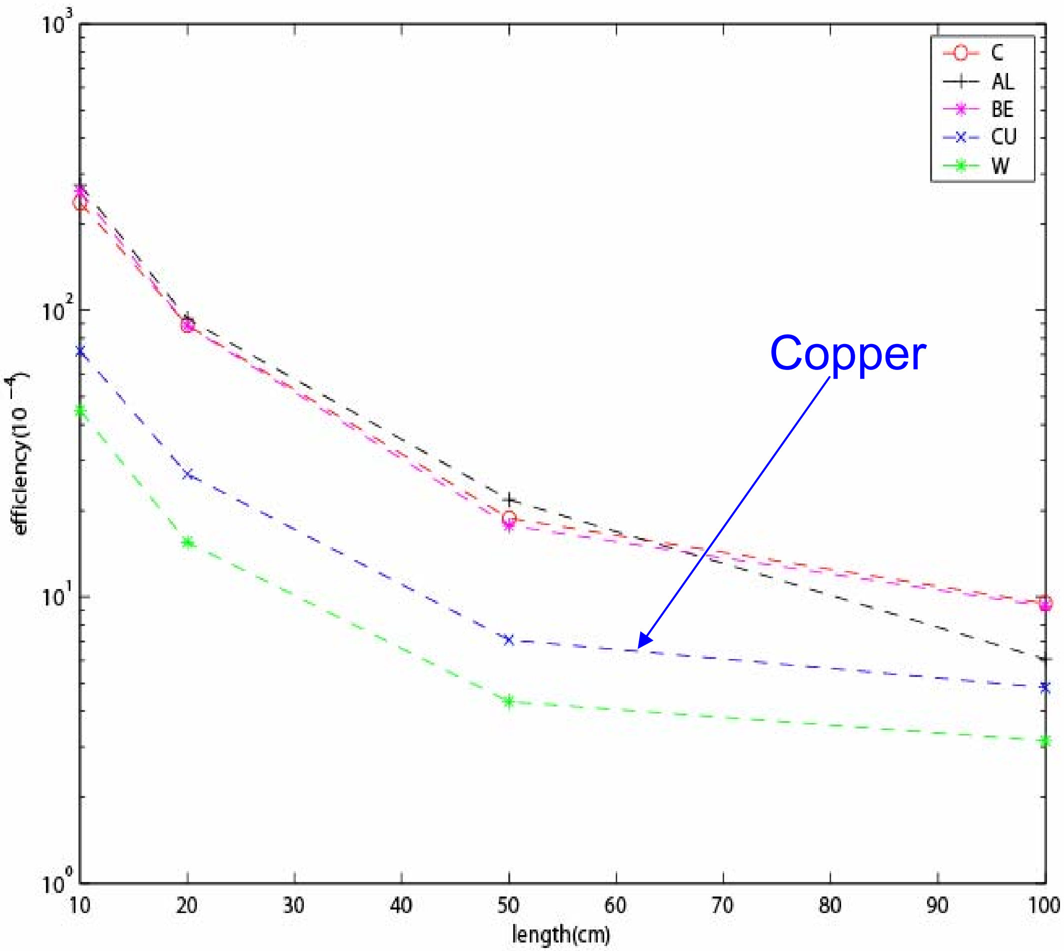
Impedance Limits Luminosity
Carbon Collimators Dominate Impedance





Study of Material for Secondary Collimators

Yunhai Cai



- High Z materials improve system efficiency
- Copper being considered because its high thermal conductivity
- Available length is about 1 meter
- Achievable efficiency is about 3.5×10^{-4} at 10 σ
- As Sixtrack program adds absorbers/tertiary collimator we expect ~x10 improvement

Similar result was obtained by Ralph Aβmann

Four LARP Collimation Program Tasks: Address Efficiency, Reliability and Design of Phase I & Propose a possible solution for Phase II Conundrum

Use RHIC data to benchmark the code used to predict the cleaning efficiency of the LHC collimation system and develop and test algorithms for setting collimator gaps that can be applied at the LHC

Responsible: Angelika Drees, BNL [Task #2]

Understand and improve the design of the tertiary collimation system that protects the LHC final focusing magnets and experiments

Responsible: Nikolai Mokhov, FNAL [Task #3]

Study, design, prototype and test collimators that can be dropped into 32 reserved lattice locations as a part of the “Phase II Collimation Upgrade” required if the LHC is to reach its nominal 1E34 luminosity

Responsible: Tom Markiewicz, SLAC [Task #1]

Use the facilities and expertise available at BNL and FNAL to irradiate and then measure the properties of the materials that will be used for phase 1 and phase 2 collimator jaws [proposed new work package]

Responsable: Nick Simos, BNL [Task #4]

Task 2: Use RHIC Data to Benchmark LHC Tracking Codes

Scope:

- Install SixTrackwColl particle tracking code at BNL and configure it to simulate RHIC performance for both ions and protons.
- Take systematic proton and ion data and compare observed beam loss with predictions
- Test (and perhaps help to develop) algorithms proposed for the automatic set up of a large number of collimators

Resources Required:

- 50% postdoc/student + supervision + travel

Timescale:

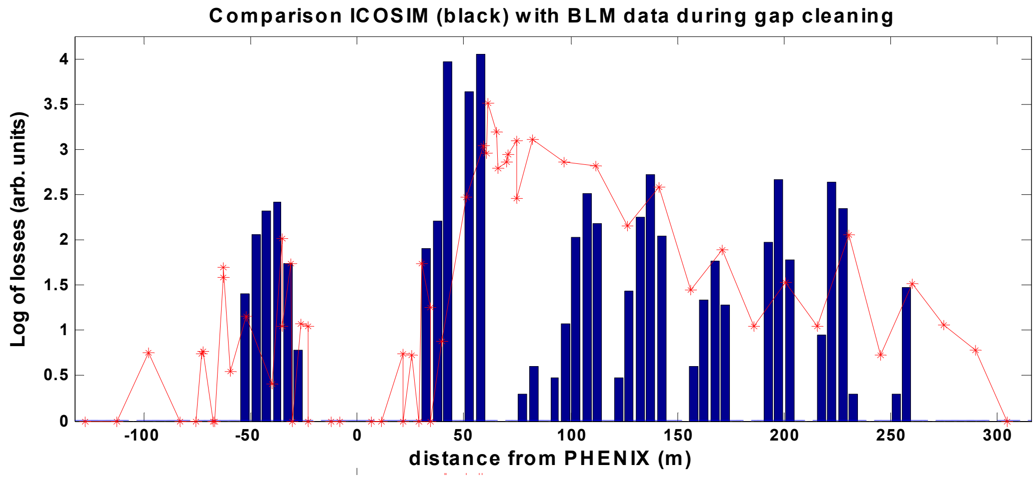
- Now until LHC beam commissioning

Comments

- Preliminary data taken; comparison programs being improved
- Postdoc search ongoing

RHIC Ion Tracking Results

Ions Agree



First look at parasitic data using a simpler ion-specific tracking code

- BLM data from abort gap cleaning during a physics run
- More data with better controlled conditions are available now for Cu
  - loss maps with only one collimator in and all others out,

Compare to “ICOSIM”, a simpler ion-specific code than SIXTRACK

- Data analysis by H. Braun (CERN)
- Import code to BNL for the short term
- Ultimately plan to merge ion specific parts of code with SIXTRACK

Reasonable agreement observed

- Ions typically do NOT make multiple turns around ring

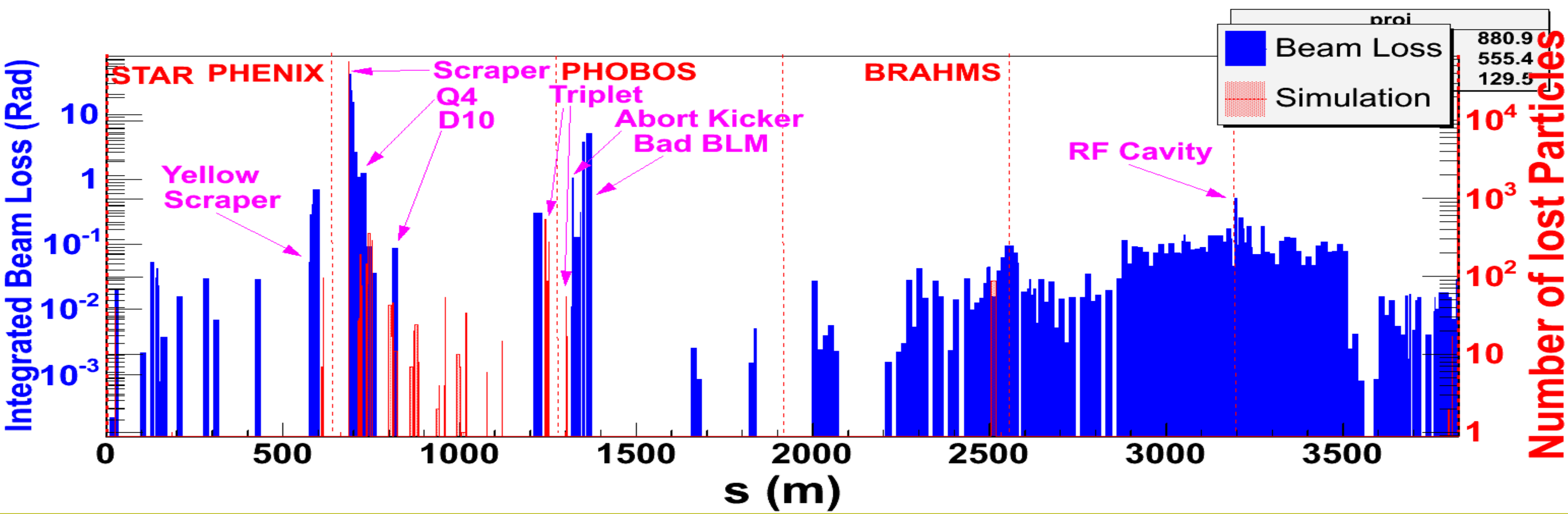
RHIC Proton Tracking Results

Physics run log file data compared to legacy "Teapot" & "K2" codes

- Poor agreement
- Devoted data with better controlled conditions will be taken
- Codes have known problems + multi-turn tracking more challenging

SIXTRACK code being tailored for RHIC lattice by CERN student NOW

Protons Data does not agree



Task 3: Model tertiary collimators at the LHC experimental insertions

Scope:
- CERN FLUKA team occupied with collimation system performance throughout ring and need help understanding beam loss & backgrounds at the EXPERIMENTAL AREAS
- MARS team at Fermilab experienced & well equipped

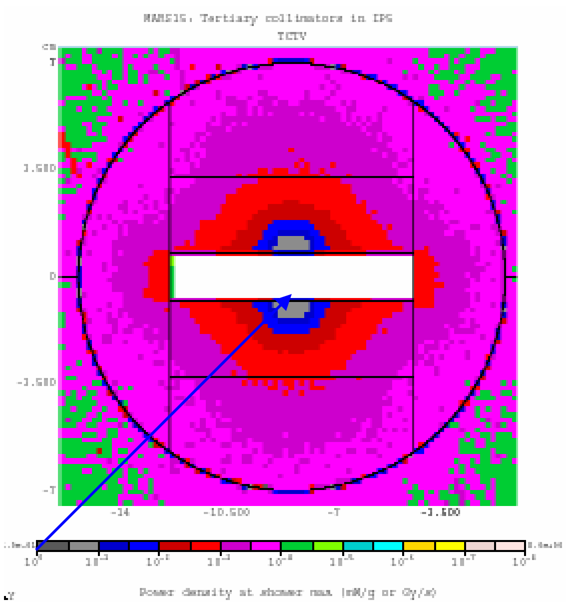
Resources Required:
- 25% postdoc + supervision + travel

Timescale:
- Now until LHC beam commissioning

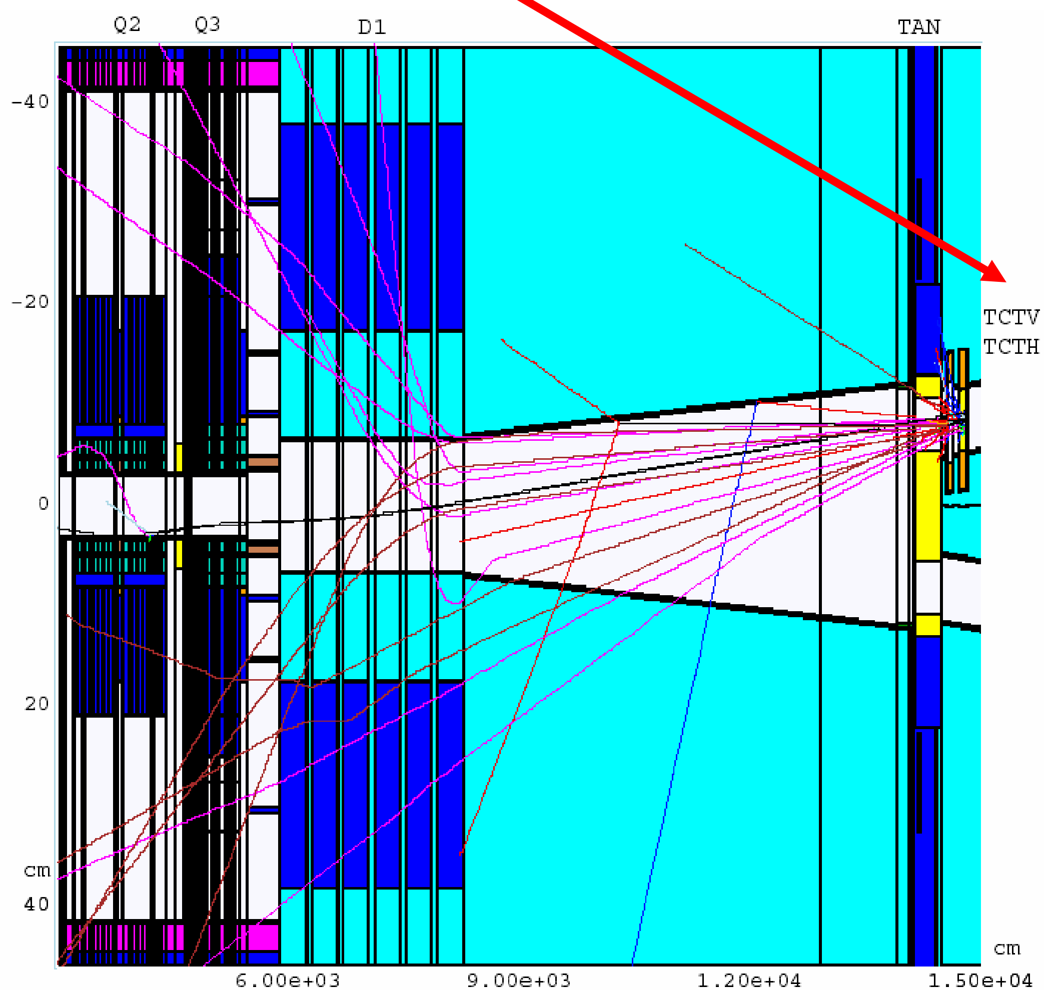
Status
- Initial results promising; More detailed simulations planned
  - Determine Efficiency of TCT and Relative performance of W vs. Cu
  - Engineering Studies, Accident Studies, More realistic Halo, Sensitivity studies

Modeling tertiary collimators in IP5 and CMS

1m Cu TCTV and TCTH @ z~150m
25mm x 80mm jaws @ 8.4σ

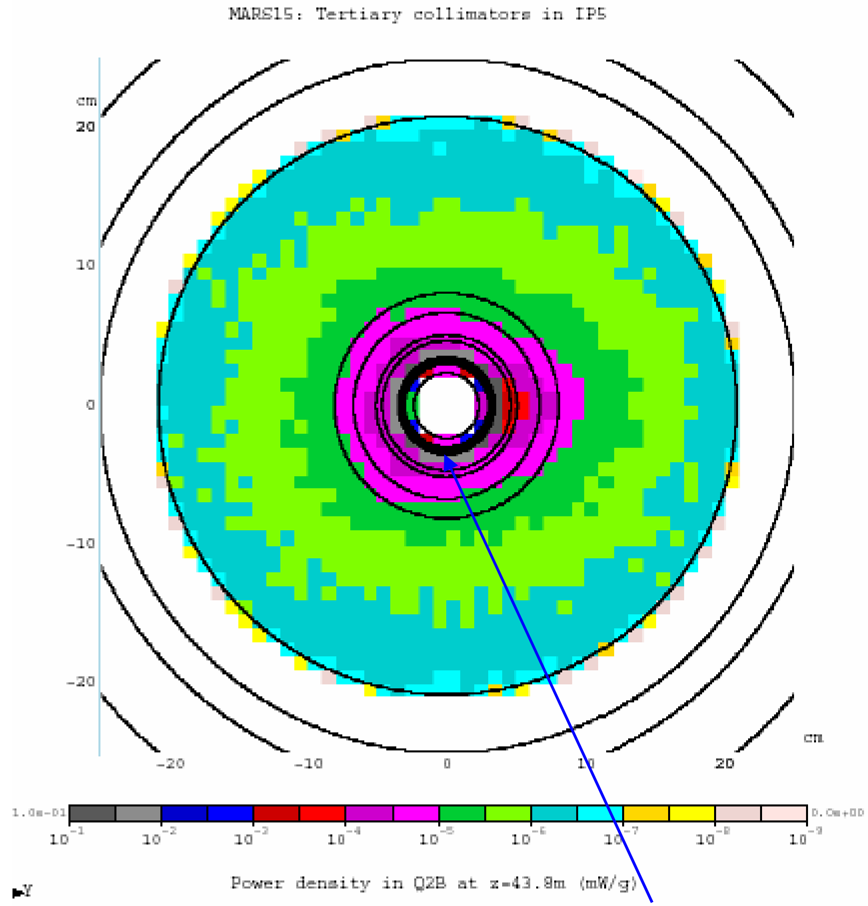


1mW/gm @ 10^6 p/s

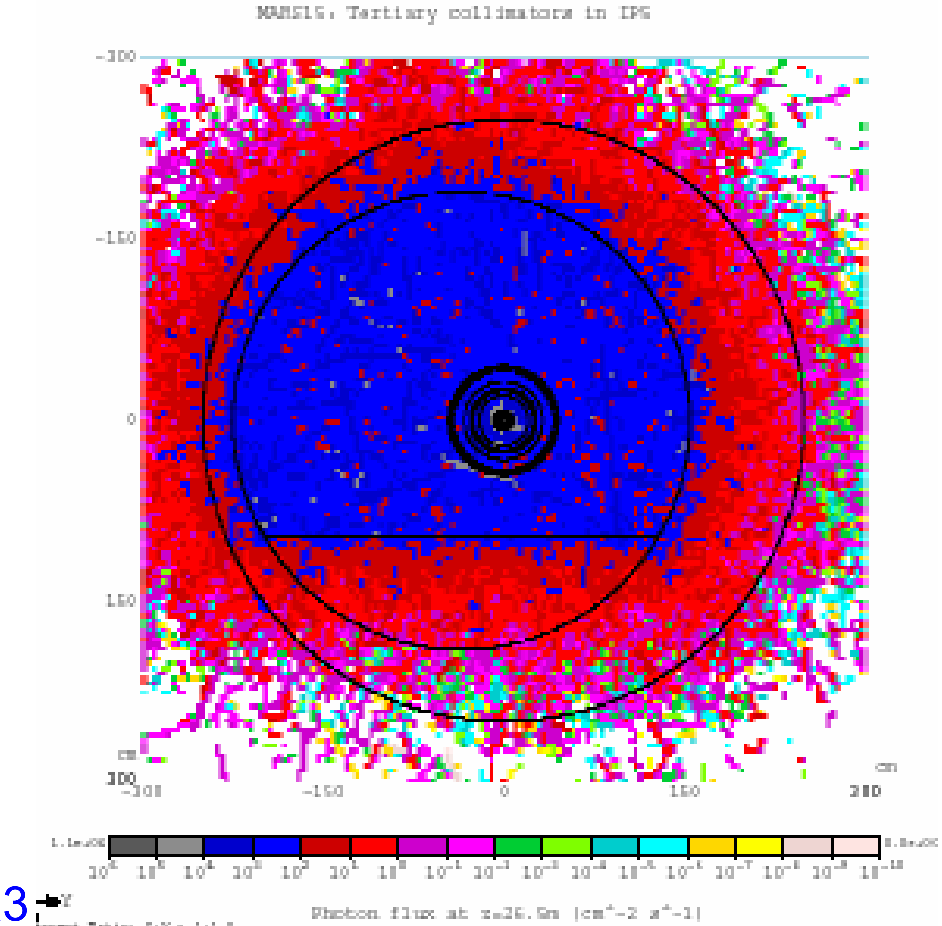


150m

TCT-Induced Energy Deposition in Triplet Quads and Backgrounds entering CMS/ATLAS



Photon Flux



Peak Energy deposition of 0.35mW/g in Q3 SC coils at β_{MAX} @ z~50m @ 10^6 p/s and design spec of $\Delta Q<0.53$mW/gm $\rightarrow$ max loss rate at TCT ~ 2 x 10^6 p/s

~1000 photons/cm2/s @ 10^6 p/s scraped ~ physics backgrounds

Task#1: Studies of a rotating metallic collimator for possible use in LHC Phase II Collimation System

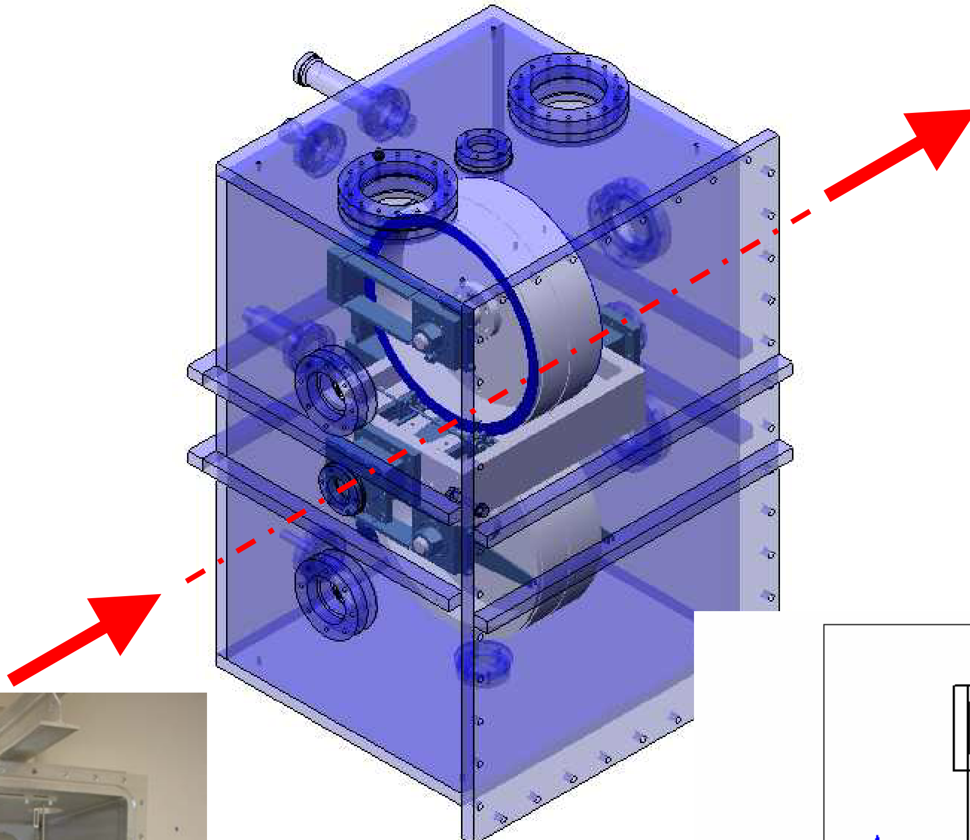
If we ALLOW (rare) ASYNCH. BEAM ABORTS to DAMAGE METAL JAWS, is it possible to build a ROTATING COLLIMATOR

– that we can cool to ~<10kW, keeping $T<T_{FRACTURE}$ and $P_{H2O}<1$ atm.
– that has reasonable collimation system efficiency
– that satisfies mechanical space & accuracy requirements

Scope:

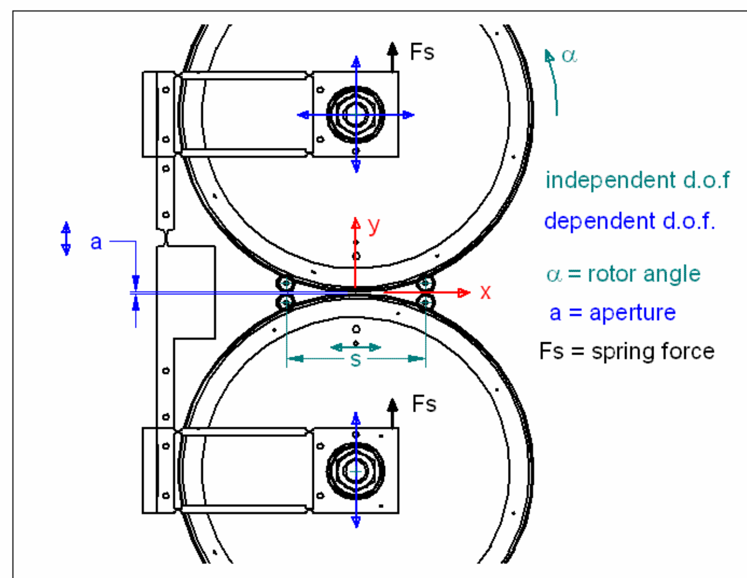
– Tracking studies to understand efficiency and loss maps of any proposed configuration (SixTrack)
– Energy deposition studies to understand heat load under defined "normal" conditions & damage extent in accident (FLUKA & MARS)
– Engineering studies for cooling & deformation
– Construct 2 prototypes with eventual beam test at LHC in 2008
– After technical choice by CERN, engineering support
– Commissioning support after installation by CERN

SLAC NLC "Consumable Spoiler" as Prototype for Phase II LHC Secondary Collimator



Differences LC / LHC:

- **Jaw length**
  - **10cm→100cm**
- **Maximum gap &**
  - **2mm → 6cm**
- **Power deposited**
  - **10W →10kW**



Task#1: Timescale & Manpower

FY 2004:	Introduction to project
FY 2005:	Phase II CDR and set up of a collimator lab at SLAC
FY 2006:	Design, construction & testing of **RC1**
FY 2007:	Design, construction & no-beam testing of **RC2**
FY 2008:	Ship, Install, Beam Tests of RC2 in LHC May-Oct 2008 run
FY 2009:	Final drawing package for CERN
FY 2010:	Await production & installation by CERN
FY 2011:	Commissioning support

RC1=Mechanical Prototype; RC2: Beam Test Prototype

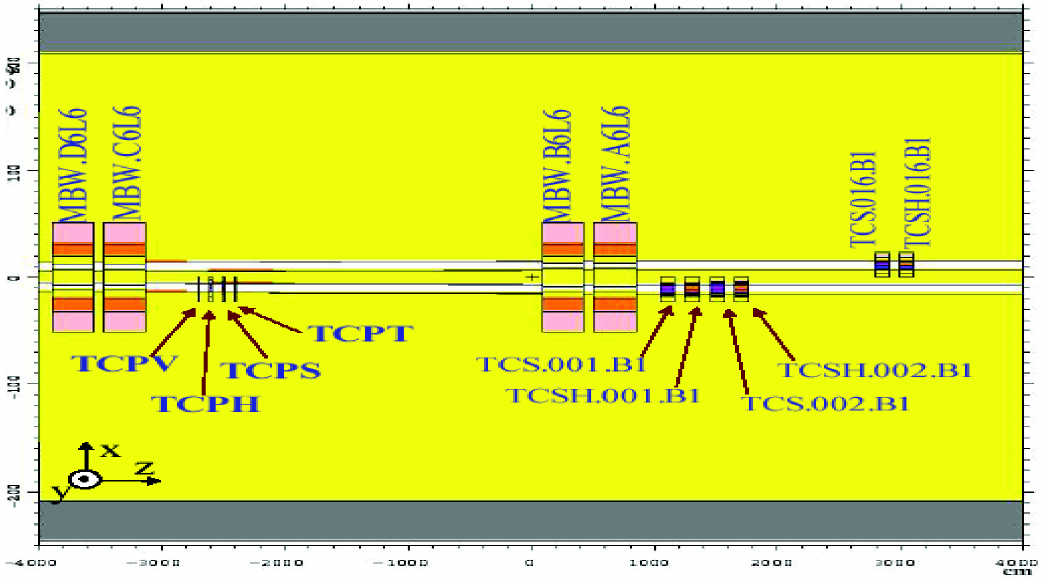
Active Manpower:
Eric Doyle-Engineering
Lew Keller-FLUKA
Yunhai Cai-Tracking
Tom Markiewicz- Integration

Meeting/advice:
Tor Raubenheimer
Andrei Seryi
Joe Frisch

Future Effort:
Controls Engineer
Designer

Planned hires:
Mech. Engineer#2
Postdoc#1

Energy Deposition in Metal Phase II Secondary Collimators w/ Carbon Phase I Collimators Open



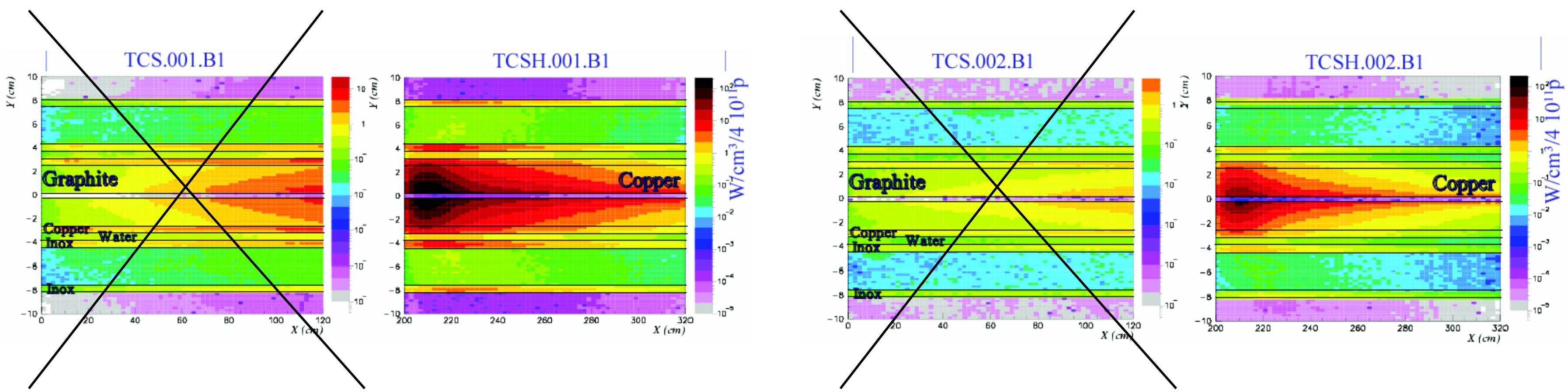
Jaws at 10 sigma

"Pencil" Beam with 80:5:5:10 loss model

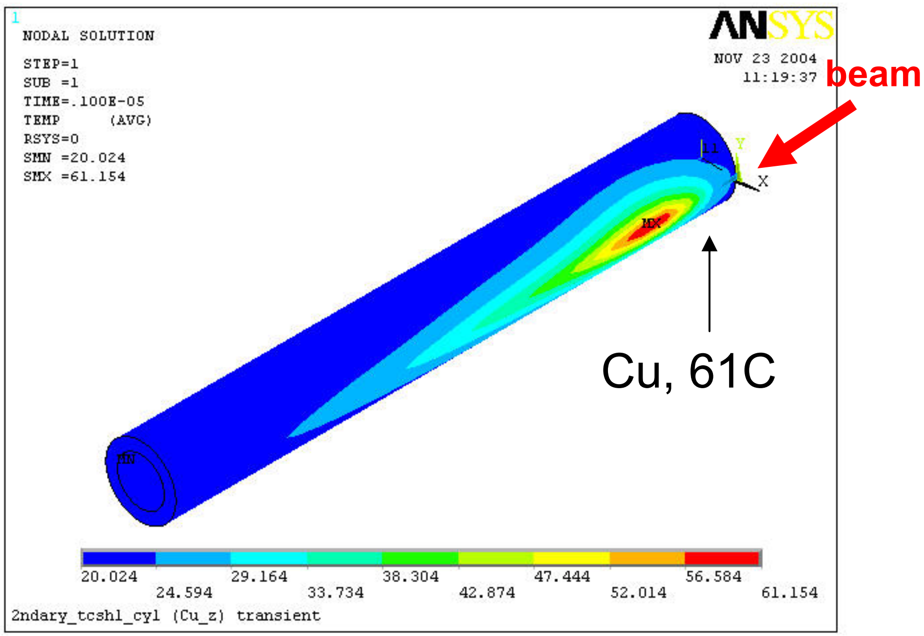
Only 1 TCSH in current (v6.5) collimation configuration

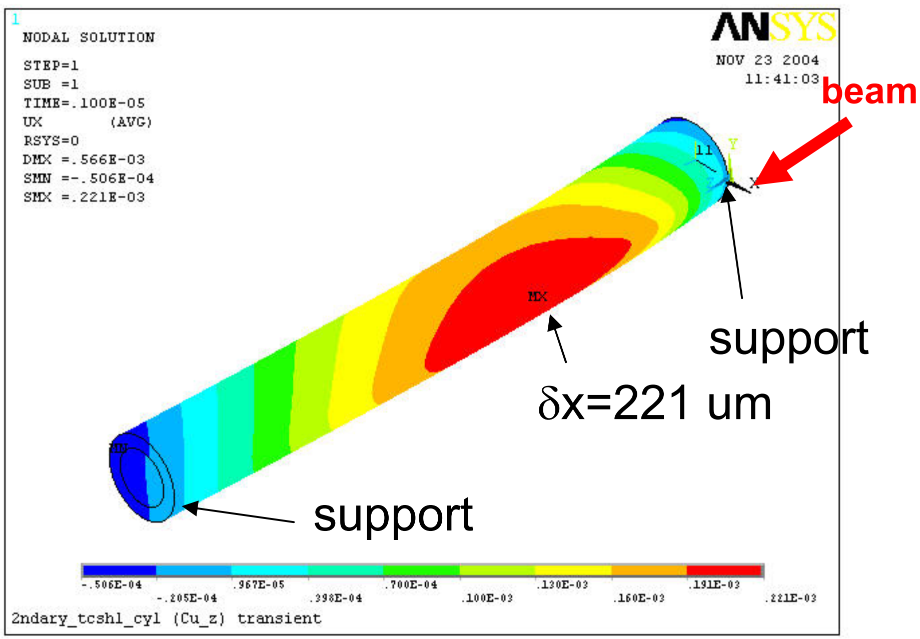
Study E_dep vs. jaw Z

- alloys, coatings, etc.



ANSYS 3D Time Dependent Thermal Distortion Simulations of 15cm OD, 1.2m long cylindrical jaws





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Material Comparison for SS 90kW & Transient 450kW

Low Z good for heating; bad for efficiency

Short bends less than longer

LHC Thermal Deflection Spec. is 25um

90kW ~OK

450kW-10s Not OK

Note: Green shading: meet our suggested alternative spec of 50um for SS and 200um (10s) for the transient.

10 □, primary debris + 5% direct hits		SS @ 1 hour beam life				transient 10 sec @ 12 mi		
material	cool arc (deg)	P (kW) per jaw	Tmax (C) [3]	Tmax water side (C)	defl (um) [4]	P (kW)	Tmax (C)	defl (um) [4]
BeCu (94:6)	360	0.85	24		20	4.3	41	95
Cu	360	10.4	61	43	221	52	195	829
Cu - 5mm wall	360	4.5	42	39	117	22.4	129	586
Cu/Be (5mm/20mm)	360	5.3	53		161			
Super Invar	360	10.8	866 [1]		152			
Inconel 718	360	10.8	790		1039			
Al	360	3.7	33		143	18.5	73	527
2219 Al	360	4.6	34	26	149	23	79	559
C R4550	360	0.6	25		5	3.0	41	20
BeCu (94:6)	90	0.85	25		8	4.3	41	86
BeCu (94:6)	45	0.85	27		2	4.3	46	101
Cu	45	10.4	89	67	79	52	228	739
Cu - solid	45	10.4	85	65	60	52	213	542
Cu - solid, 1/2 long	45	8.1	86		46	41	214	305
2219 Al	45	4.6	43		31	23	89	492
Al - solid	45	3.7	40.8		31	18.5	80	357
7 □, no pre-radiator								
Cu - solid	45	15.8	113	80	93	79	297	855
Cu 30/90 front 30	45	6.6	118	88	27	33.2	302	178
Cu 30/90 back 90	45	9.2	87		12	46	211	288
7 □, carbon pre-radiator								
Cu - solid	45	14.3	127	85	44	72	333	558
Cu 30/90 front 30	45	8.2	132	98	31	40.9	339	209
Cu 30/90 back 90	45	6.1	63	47	9	30.5	140	202
W (48cm long)	45	12.4	414	207	21	62	1450	128
W 6/42 front 6	45	6	534	302	15	30	1622	68
W 6/42 back 42	45	6.4	190	72	5	32	624	35

LHC Collimator Mechanism Concept

End and center aperture stops included in same model

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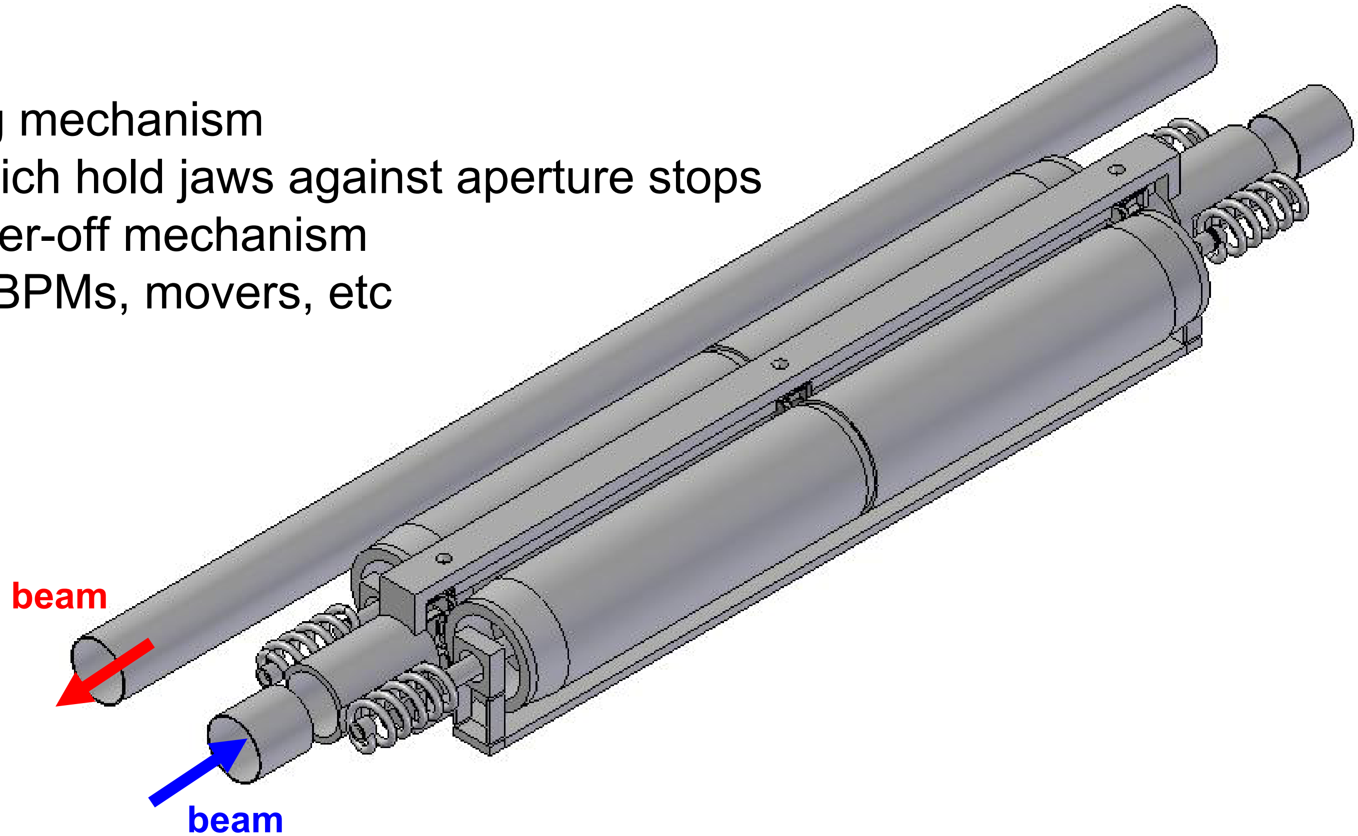
Not yet included:

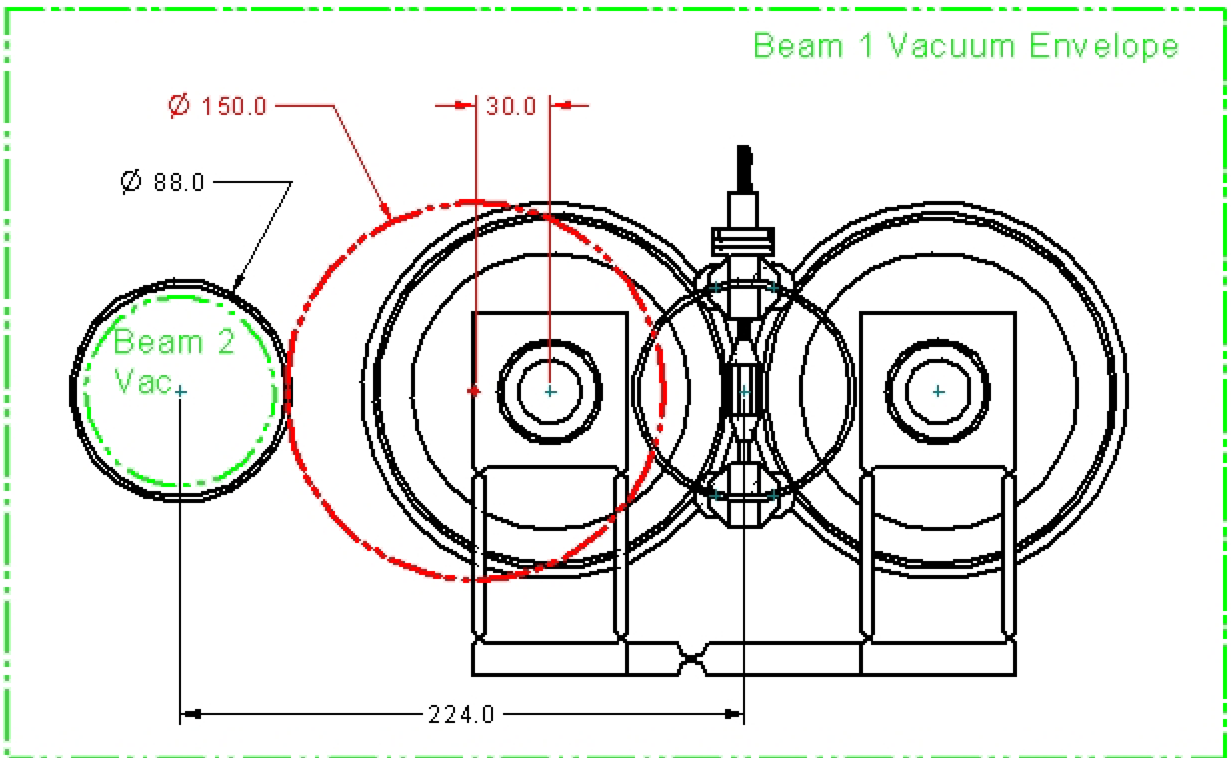
1. Rotary jaw indexing mechanism
2. Loading springs which hold jaws against aperture stops
3. Open aperture power-off mechanism
4. Vacuum chamber, BPMs, movers, etc



- Helical coolant supply tubes flex, allow one rev of jaw
- Jaws supported a both ends for stability, allow tilt control
- Alternative: jaws supported in center
  - thermal deflection away from beam
  - no tilt control

Geometrical limits due to 150mm rotor, 224 mm Beam Axis Spacing, 8.8cm beam pipe

30mm jaw travel (in red) causes jaw to intersect adjacent beam pipe. No space for vacuum chamber wall. Resolution: 1) smaller jaw diameter 2) vacuum envelope encloses adjacent beam pipe 3) less jaw motion 4) reduce diameter of adjacent beam pipe.



Status of Phase II Collimator Conceptual Design

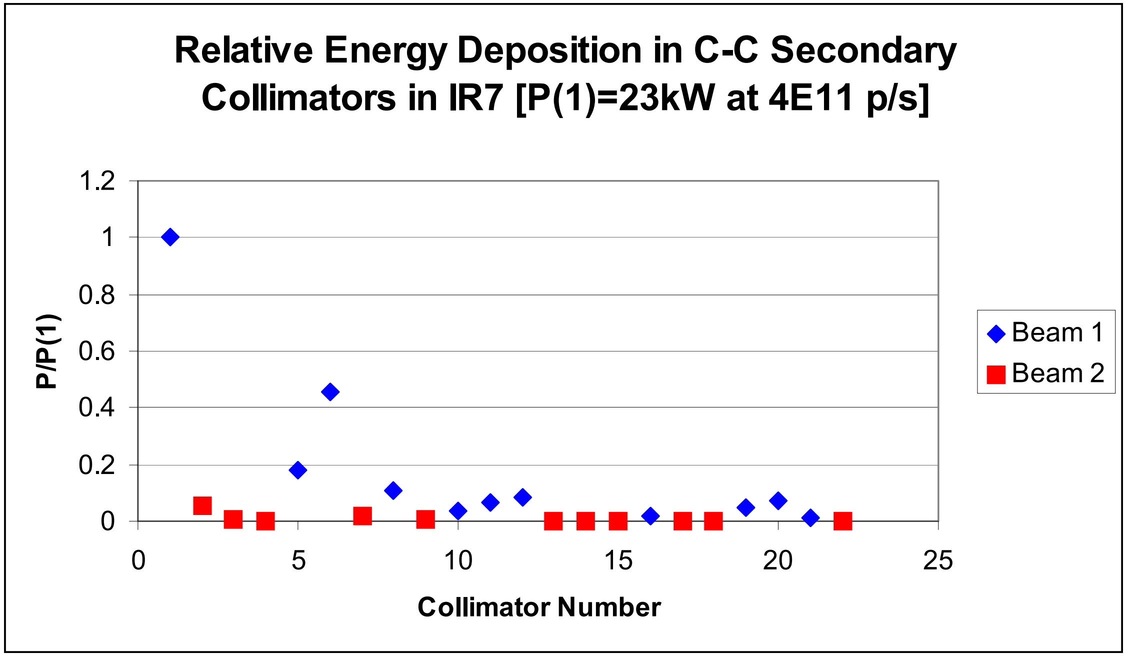
Adequate software in place and MANY studies have been done

We do NOT yet have a conceptual design we are ready to start to build

Actively investigating promising new directions

- Break the first secondary into two unequal length pieces of perhaps different materials
- Grooved “expansion slots” to limit deformation
- Adjust gaps of the first carbon & metal secondary to reduce heat load while maintaining efficiency with remainder of secondary system
- Deformation tolerance relaxed to ~> 100 um if jaws expand AWAY from beam
- 60mm gap at injection incompatible with center mounted gap adjustor
  - Look into adopting Phase I adjustment mechanism
- Spatial constraints of LHC beam pipes & tunnel a challenge
- 28 of 30 Phase II collimators will not have a heating problem
  - Keep C-C in hot position and design remainder for ~10% DC heat load

Possible Path to Immediate RC1 Prototype: Leave TCS#1 Carbon-Carbon, Remainder Cu



Inefficiency	1C-10Cu	All Cu
Horizontal	2.84×10^{-4}	3.72×10^{-4}
Vertical	3.63×10^{-4}	4.36×10^{-4}
Skew	4.57×10^{-4}	3.85×10^{-4}

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Interaction of Phase II Project with CERN

Collaboration

- Monthly video meeting with active discussion
- Transfer of codes & drawings
- Phase II collaboration meeting June 15-17 at SLAC with adequate CERN engineering and simulation expertise present to ensure that RC1/RC2 specs meet LHC requirements and constraints

CERN Phase II program is beginning

CERN will concentrate on alternative metal designs

e.g. Design based on rolls of sheet metal has been mentioned

A decision on which course to pursue will be taken after operational experience with Phase I system, LHC performance, and beam tests of several prototype designs are considered

Task #4: Radiation tests of LHC PHASE I & II collimator materials

Scope:

Irradiate 2-d weave carbon-carbon used in Phase I jaws plus materials considered viable for Phase II jaws

- BLIP (BNL Linac Protons): 70 μA of 200 MeV protons
  - 120 GeV protons behind pbar target at FNAL also available

Measure material properties: resistivity, thermal expansion, mechanical properties, thermal conductivity/diffusivity and resilience to thermal shock

- BNL Hot Cell Sample Measurement Facility

Resources Required:

– BLIP Irradiation charges & hot cell measurement facility use fees

– Sample prep & measurement apparatus improvement

Timescale:

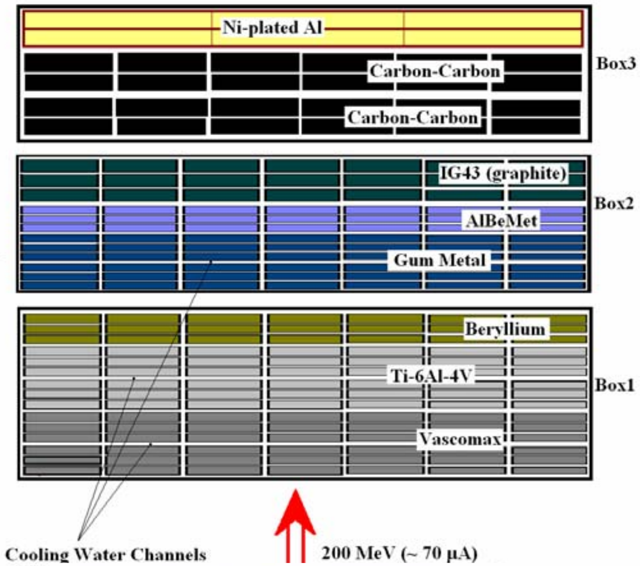
– 2005,2006 proton runs + analysis into FY2007

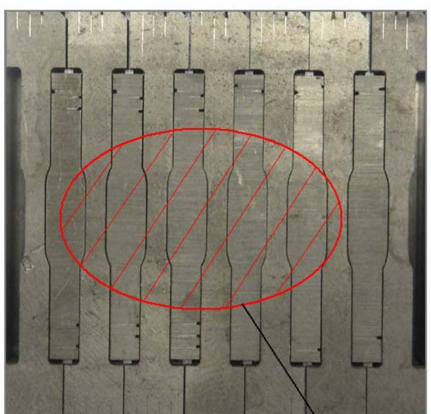
Status

– Carbon-carbon samples now under irradiation since 29 April 2005

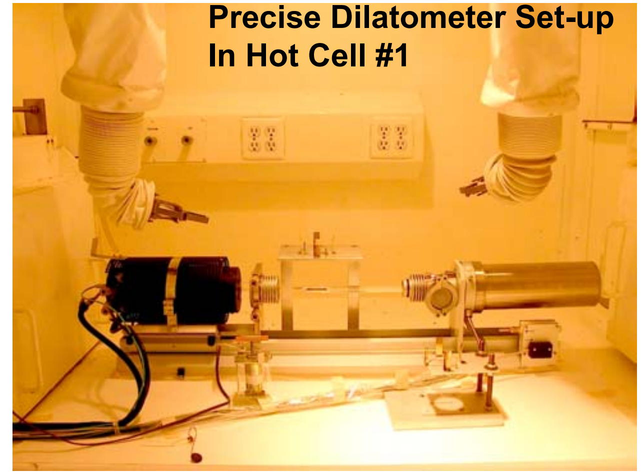
BNL Irradiation (BLIP) and Post-Irradiation Testing Facilities and Set-Up

Layout of multi-material irradiation matrix at BNL BLIP

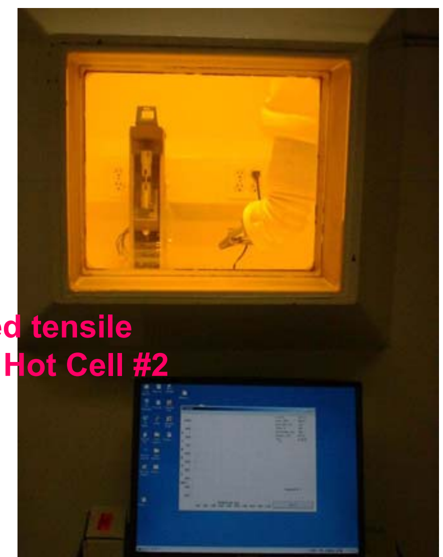




Test Specimen Assembly



Precise Dilatometer Set-up In Hot Cell #1



Remotely-operated tensile testing system in Hot Cell #2

Why?
Key Material Properties Can Change Drastically with Irradiation

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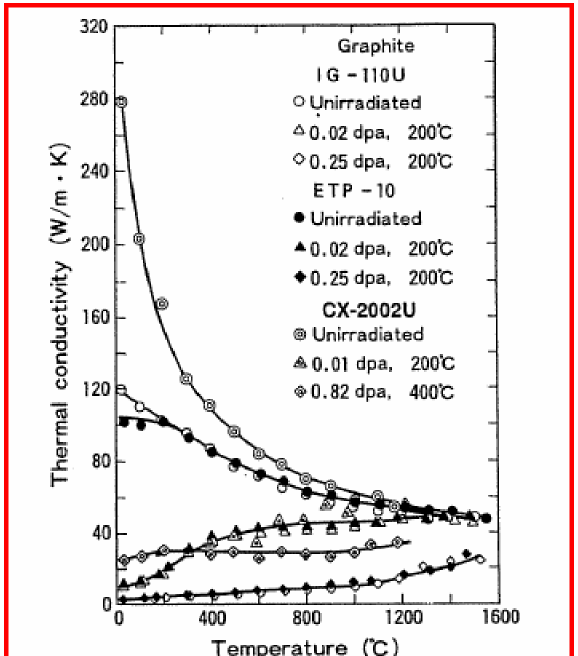
Note the x10-30 Change in Thermal Conductivity in certain types of graphite and CC composites after minimal exposure

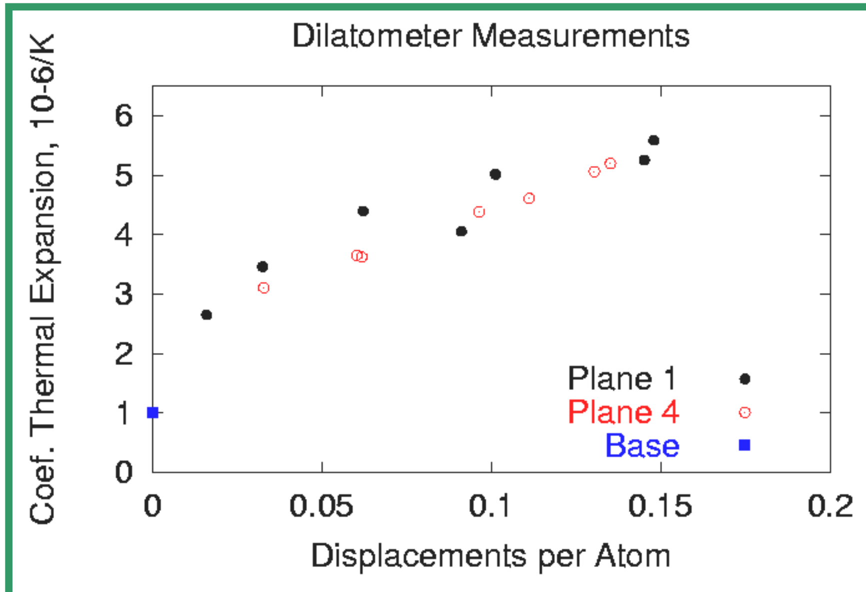
Thermal conductivity and dimensional change of neutron-irradiated graphites IG-110U, ETP-10 and GC-30

Irradiation	Thermal conductivity (W/(m K))			Dimensional change (%)		
	IG-110U	ETP-10	GC-30	IG-110U	ETP-10	GC-30
Unirradiated	119	101	16	–	–	–
0.02 dpa, 200°C	10.9	11.8	3.7	0.04	0.10	−0.14
0.25 dpa, 200°C	2.6	3.4	1.9	0.14	0.24	−0.68



Thermal conductivity of neutron-irradiated graphites.

Super-INVAR



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FY06 Budget Planning

al,escala	Budget Type	LAB		
	Budgeted			Budgeted Total
Task	BNL	FNAL	SLAC	
1		20000	700000	720000
2	50000			50000
3		30000		30000
4	50000	0		50000
	100000	50000	700000	850000
al	100000	50000	700000	850000

Conclusion

The four LARP Collimation program tasks

- Provide R&D results to a key LHC subsystem that will need to perform well from the beginning
  - Strong support for all tasks from LHC Collimation group
- Play to the unique strengths of the US Labs
  - RHIC as a testbed
  - BNL irradiation test facilities
  - Fermilab's simulation strength
  - SLAC's LC collimator engineering program

Technical Appendix
Phase II Secondary Collimator Task

Status of Phase II Efficiency Studies

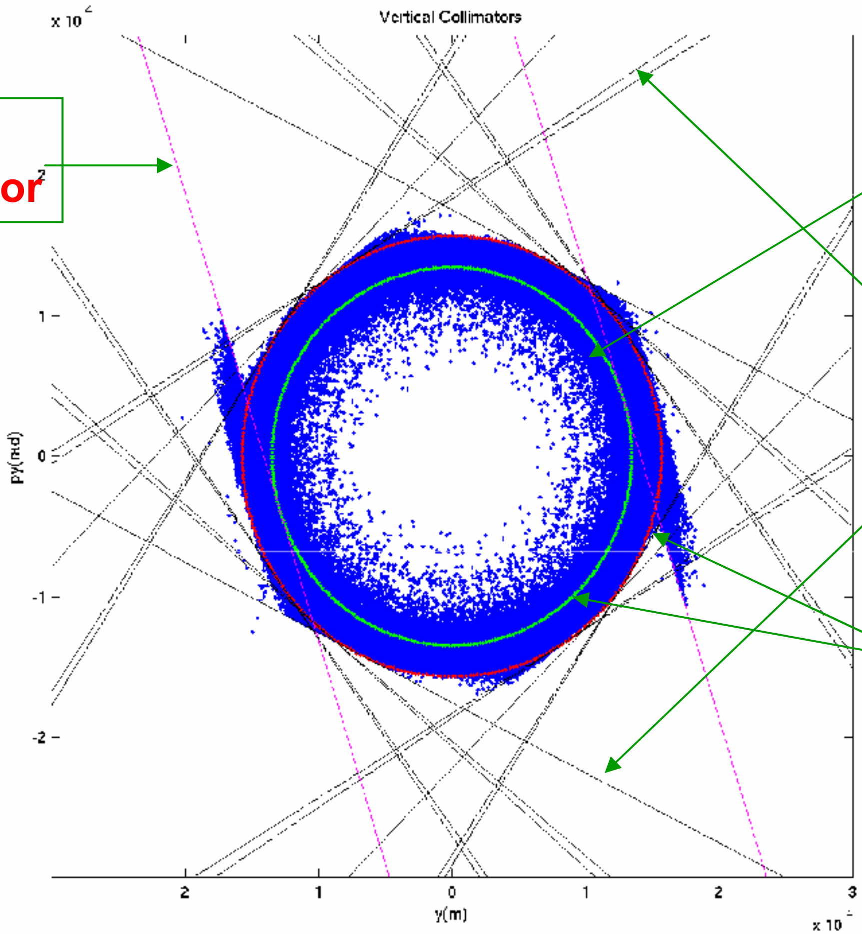
Excellent understanding of the code:

– Tracking simulations of 1m metal secondary collimators at 7σ show inadequate efficiency (previously shown plot)

– CERN provided upgraded code with absorbers & tertiary collimators added will hopefully show adequate performance

– Continue to understand playoff between gaps, lengths and materials and provide loss maps for use as FLUKA input for suggested modifications

Vertical & Skew Collimators



Primary collimator

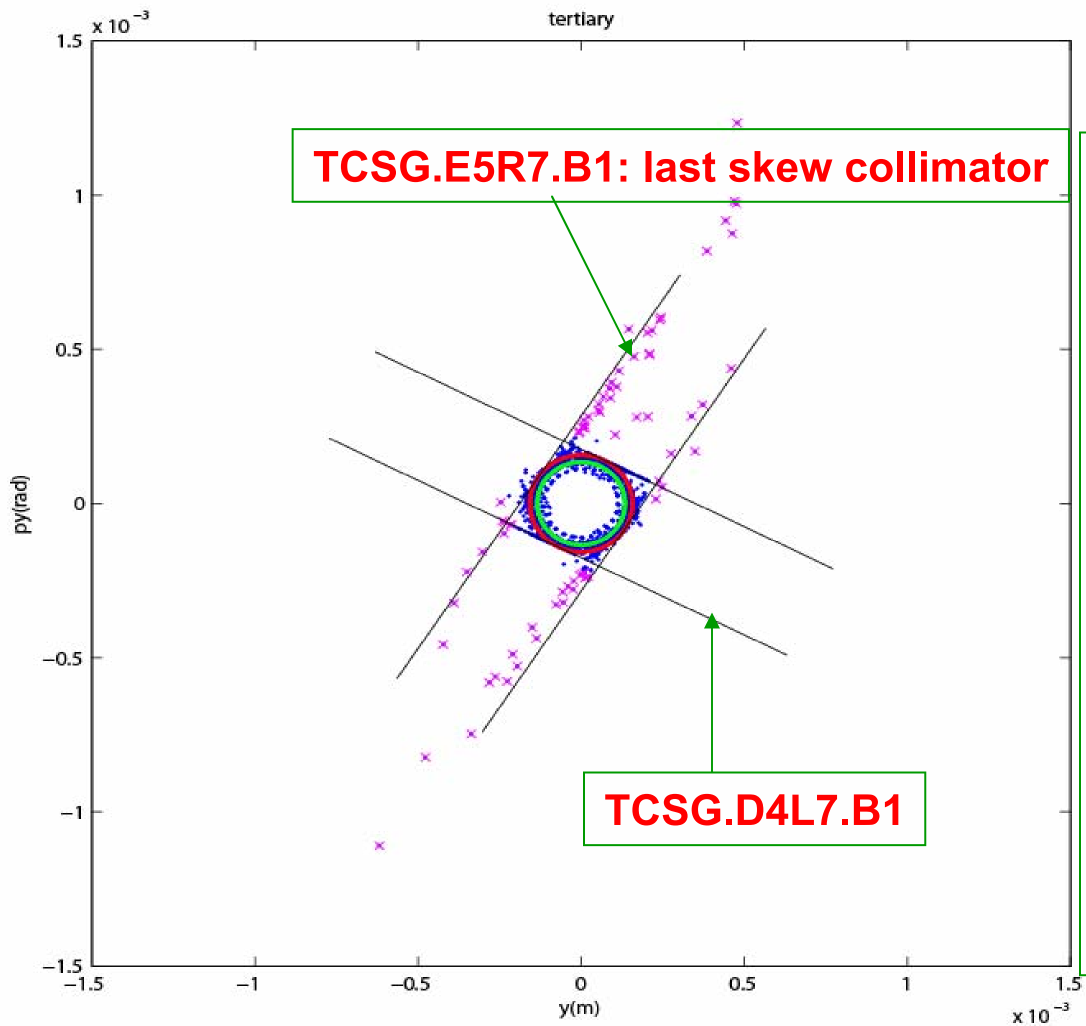
Secondary halo in normalized phase space at the end of collimation system

Collimators are projected to The end of collimation system

6 and 7 sigma contours

This is an independent check of the simulation code, since the collimators are plotted according to the lattice functions calculated using MAD.

Tertiary Halo: Particles Escaped from the Secondary Collimators



Number of particles beyond 10σ is 73, which is consistent with the efficiency calculation: 73/144446 = $5\text{x}10^{-4}$.

Tertiary halo at large amplitude is generated by the large-angle Coulomb scattering in the last collimator.

If we add a tertiary collimator at 8σ in the same phase as the collimator: TCSG.D4L7.B1 after the secondary collimators, the efficiency should be better than $1\text{x}10^{-4}$.

Inefficiency of phase 2 collimation of LHC when 1st Secondary is Carbon-Carbon & the remaining Secondaries are Copper

	Hybrid	Cu
Horizontal	2.84×10^{-4}	3.72×10^{-4}
Vertical	3.63×10^{-4}	4.36×10^{-4}
Skew	4.57×10^{-4}	3.85×10^{-4}

Status of Phase II Energy Loss Studies

FLUKA with “simple” CERN-provided input file modeling ~40m around primary collimators used for all SLAC studies

Let “pencil beam” halo interact in primary vertical carbon collimator and study energy deposition in rectangular 25x80mm jaws at 10σ

- Assume 80% inelastic int. in primary, 2.5% in each jaw of secondary
- Vary jaw material & provide energy deposition grid on jaw to ANSYS
  - 2.5mm x 8mm x 5cm rectangular grid, mapped onto cylinder
- Understand secondary particle content, energy & spatial distributions

Use CERN provided loss maps for H,V,Skew halo with jaws at 7σ and re-calculate energy deposition grids

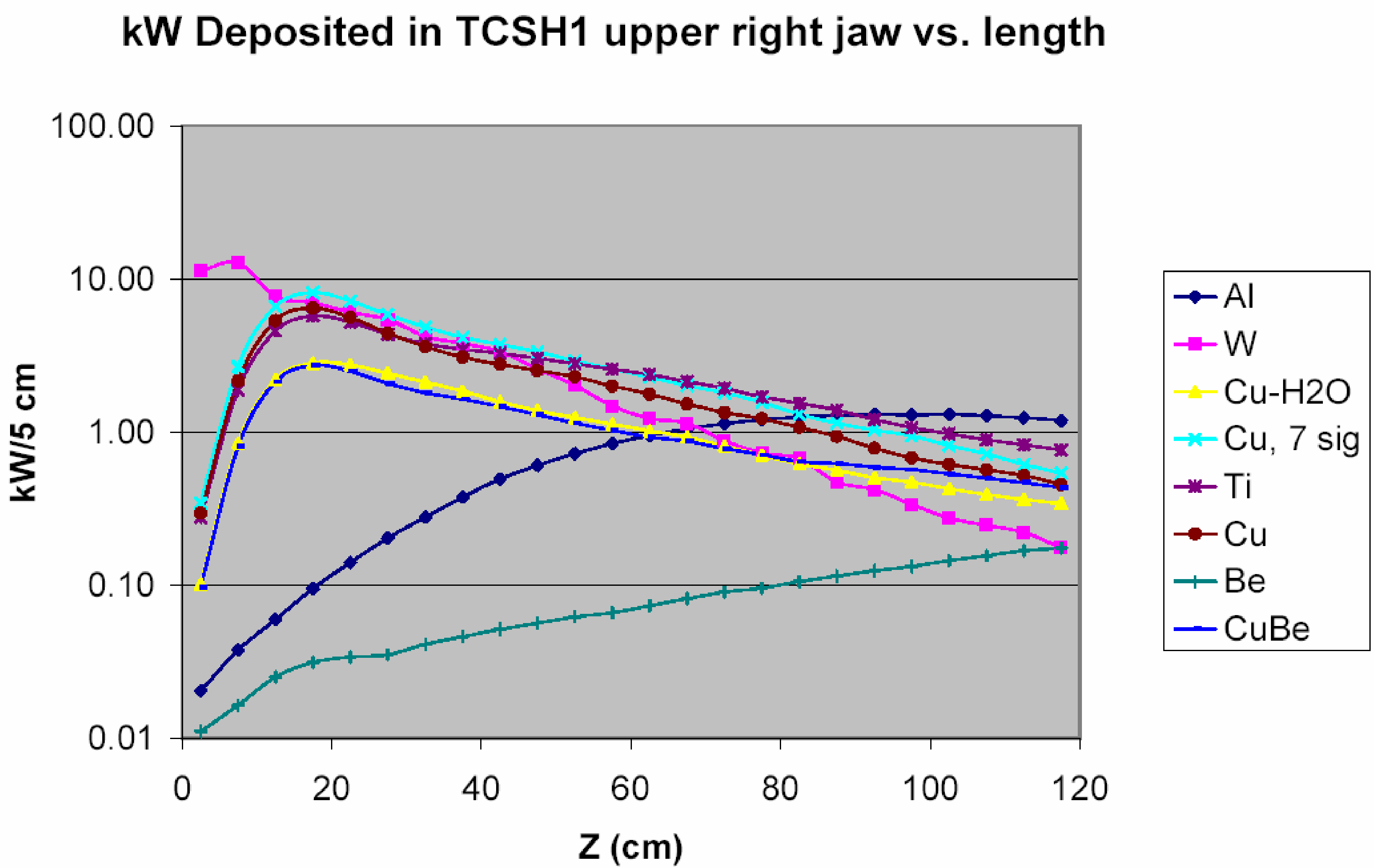
Study accident case:

- Transverse extent of damaged region

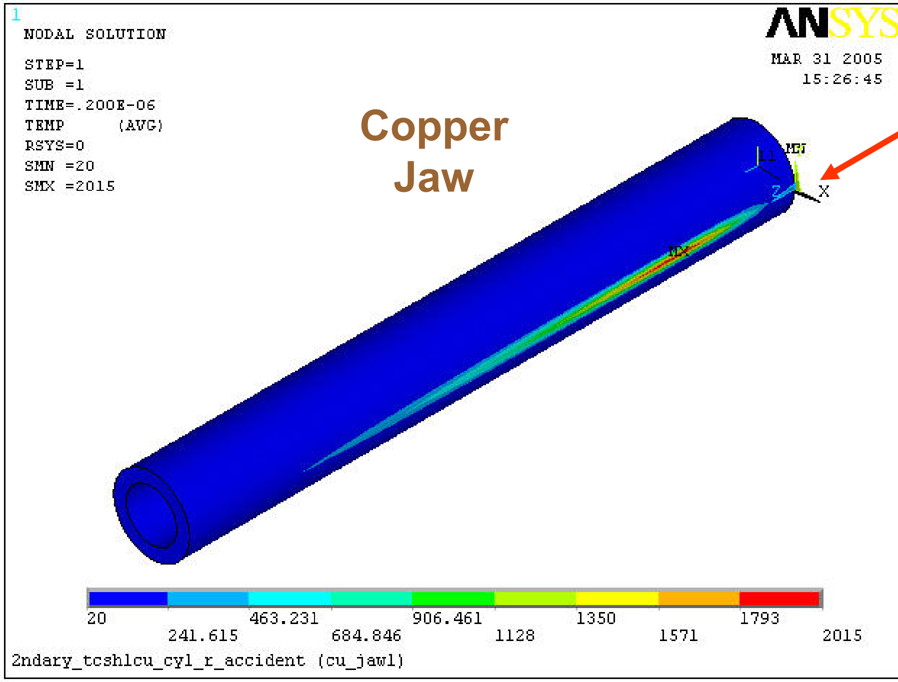
Longer term goal of upgrading to current CERN input structure with much richer description of all devices in tunnel

- For the moment, ask CERN for estimates of load on “easier” collimators

Power absorbed in one TCSH1 jaw at 10σ when 80% (5%) of 450kW of primary beam interacts in TCPV (TCSH1)



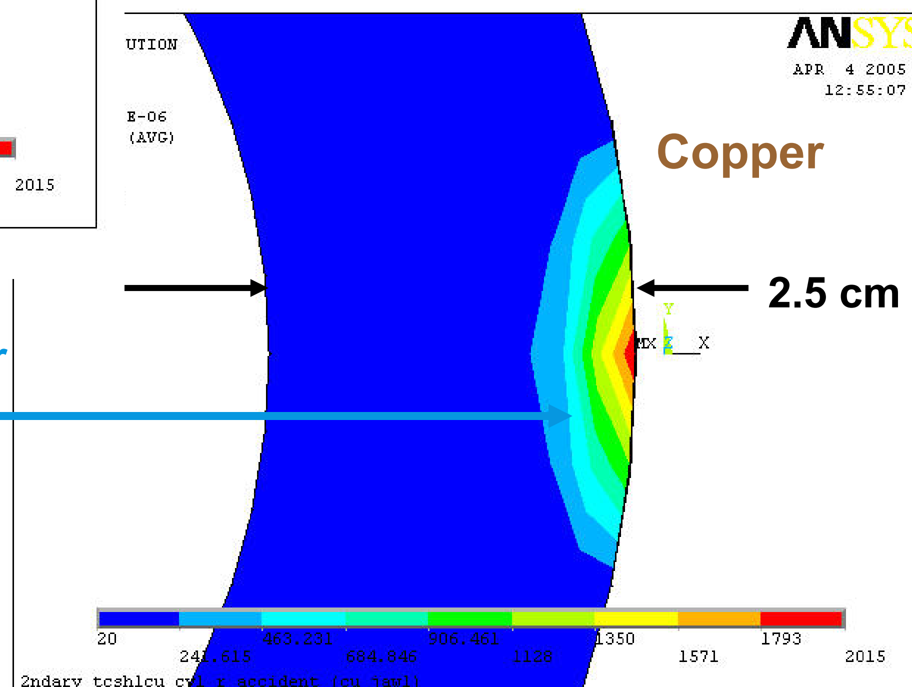
What is the damage area in a missteering accident?



Copper Jaw

Missteered beam (9E11 protons) on secondary Jaw

Cross section at shower max.



Copper

2.5 cm

Fracture temp. of copper is about 200 deg C

Assumed Damage threshold seems inconsistent with FNAL experience

Power Deposition on First Secondary Collimator in 12 Min. Lifetime (kW per jaw)

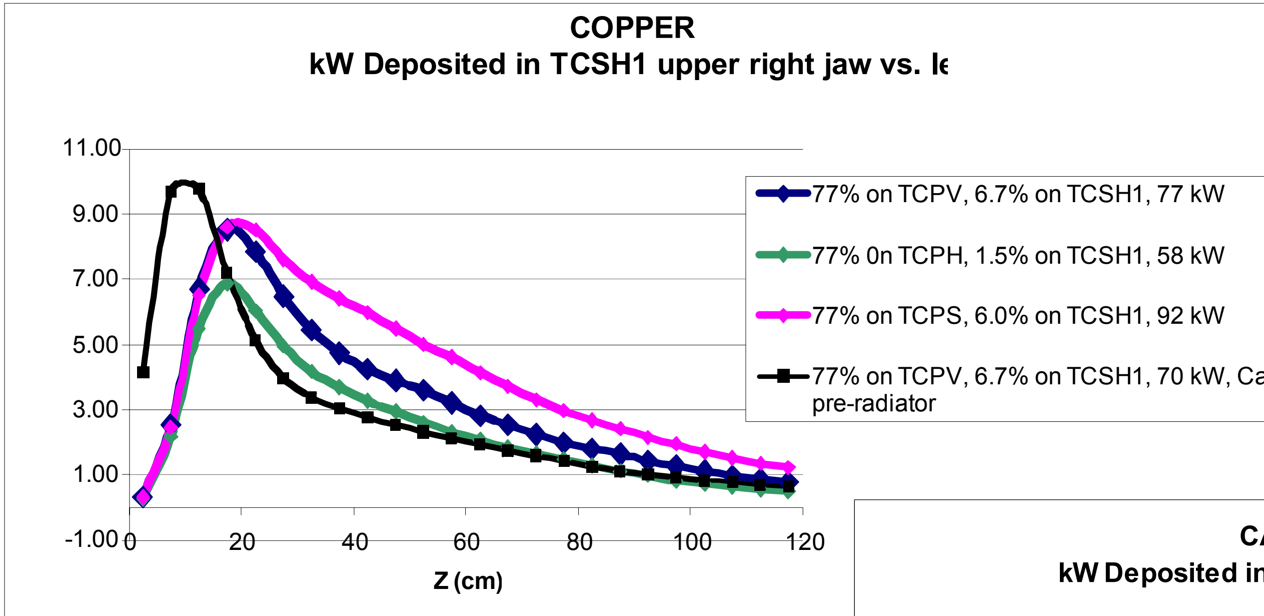
Sensitivity to aperture and to source of halo: H, V, or S

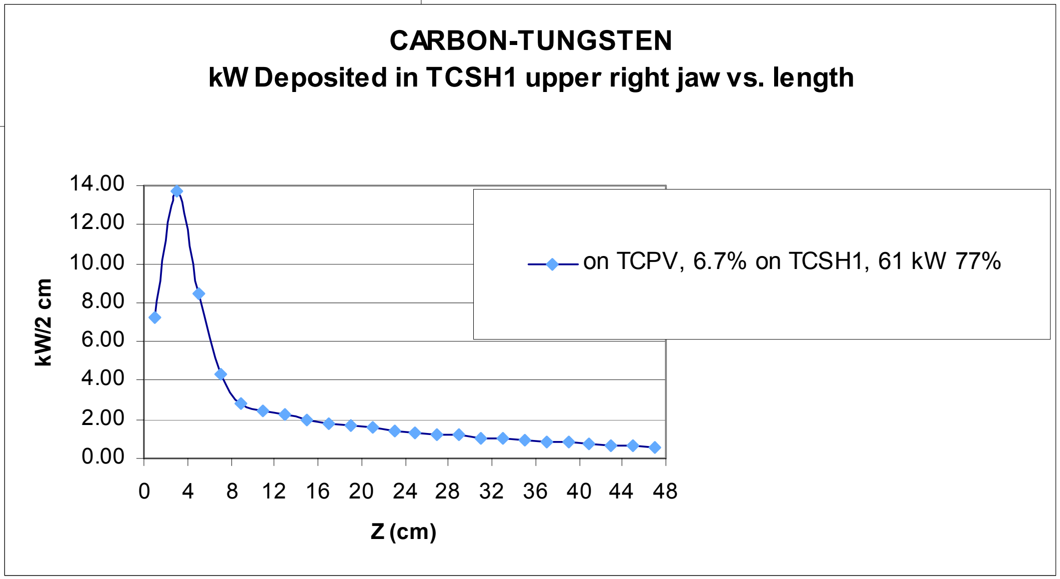
Primary Collimator (source)	TCSM.B6.L7 Jaws at 7 sigma		TCSM.B6.L7 Jaws at 10 sigma	
	Copper	Al_2219	Copper	Al_2219
TCP.D6.L7 (TCPV)	73	26	51	19
TCP.C6.L7 (TCPH)	61	22	49	19
TCP.B6.L7 (TCPS)	92	28	56	20

Notes:

1. Collimator data, ray files, and loss maps from LHC Collimator web page, Feb. 2005.
2. Must add contribution from direct hits on secondary jaws.

Concentrating E_dep in Front Part of Jaw





Status of Phase II Engineering Studies

Sophistication of ANSYS calculations progresses:

Cooling modeled as a constant heat convection coefficient (11880 W/m^2/°C) in contact with 20°C water

- Look at peak temperature
- Power density transferred to water
  - Compare to power density at which water boils

Steady state to time dependent calculations

25x80mmx1m bars with longitudinal cooling to

150mm diameter cylinders of varying annular thicknesses

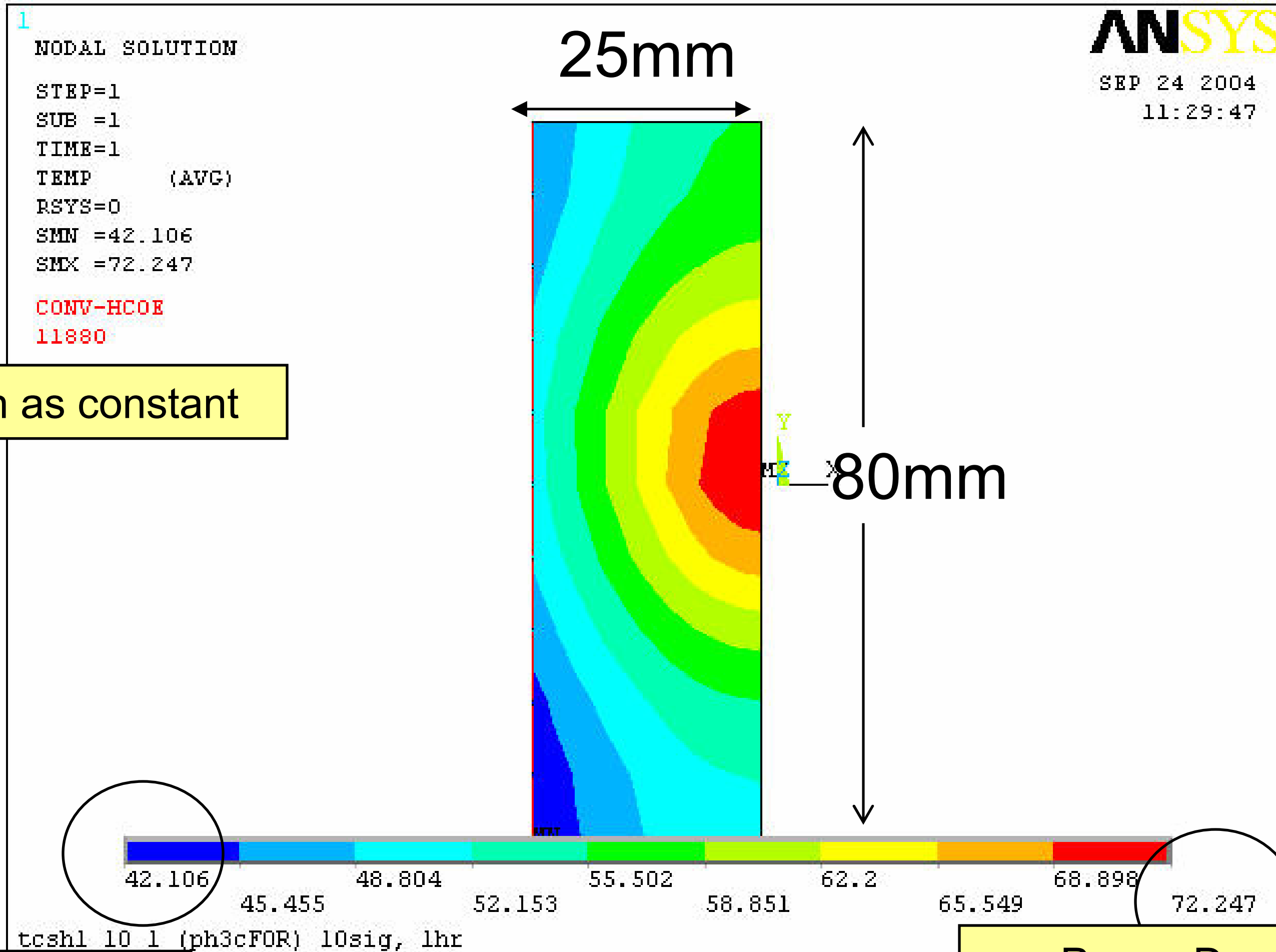
- Azimuthally wound cooling to lower peak T
- Longitudinal cooling over limited azimuth to minimize temperature difference across jaw

Extension of NLC central "datum" to adjust jaws

Does not seem to work: cannot provide jaw gap & is in the way of beam

Will try to adapt CERN Phase I adjustment mechanism to rollers

Steady State Temperature of TCSH1 at shower max when jaw at 10σ is in contact with 20°C H2O and 80% (5%) of 90kW of primary beam interacts in TCPV (TCSH1)



C_V Cu taken as constant

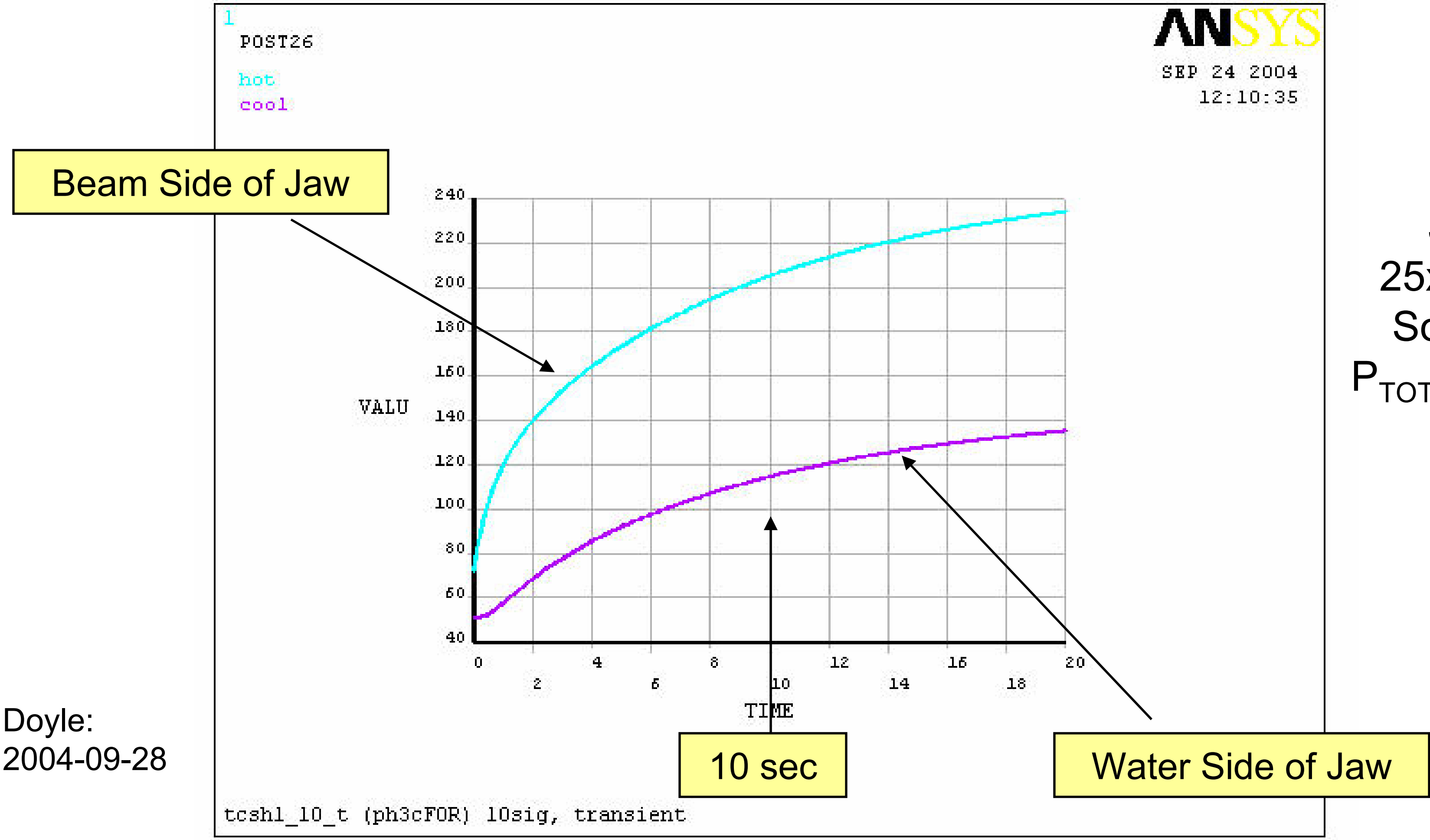
Jaw:
25x80mm
Solid Cu
P_{TOT}=1270W

Doyle:
2004-09-28

Boundary Condition:
Convection Coefficient
HC_{H20}=11880 W/m²/°C

Power Density to H2O
0.38 MW/m²
(H_2O boils at 1 atm @ 1.3E6)

Time Dependence of Peak Temperature of TCSH1 shower max when jaw at 10σ is in contact with 20°C H2O and 80% (5%) of 450kW of primary beam interacts in TCPV (TCSH1)



Jaw:
25x80mm
Solid Cu
P_{TOT}=6400W

Doyle:
2004-09-28

Grooved Cylindrical Jaw Reduces Deflection

Parameters

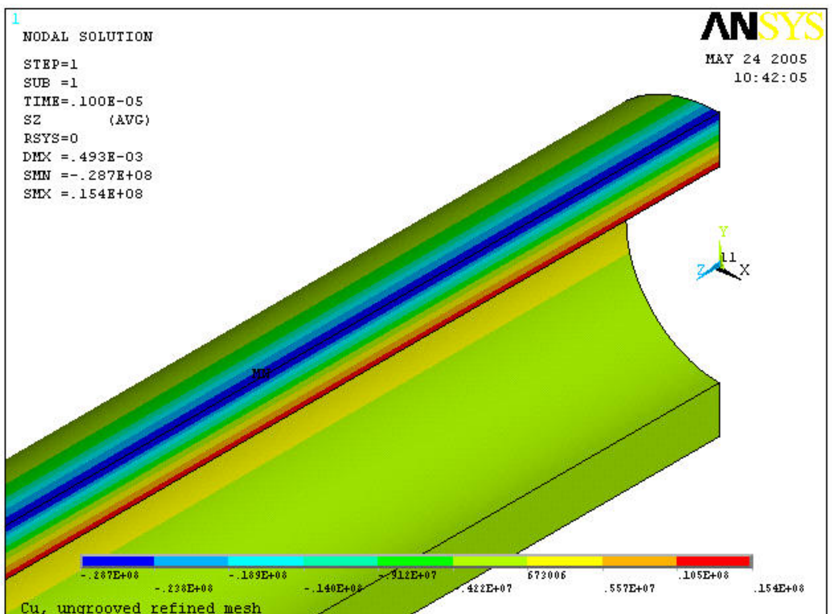
150mm O.D., 25mm wall, 120cm long

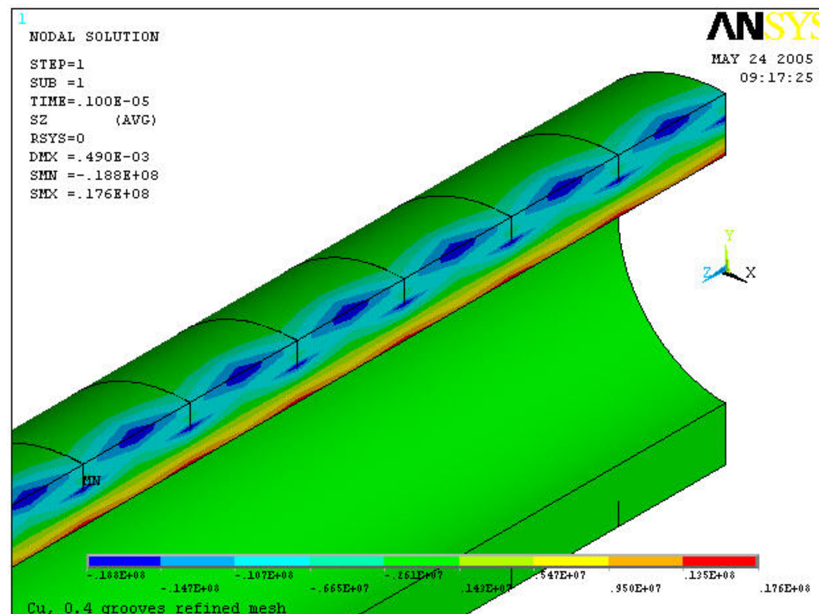
Grooves: 10mm deep, 50mm spacing

10kW heat, evenly distributed

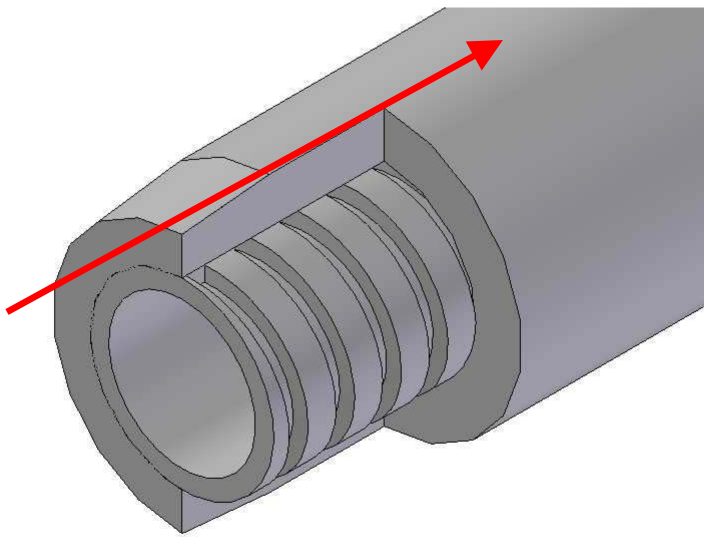
45 deg cooling arc

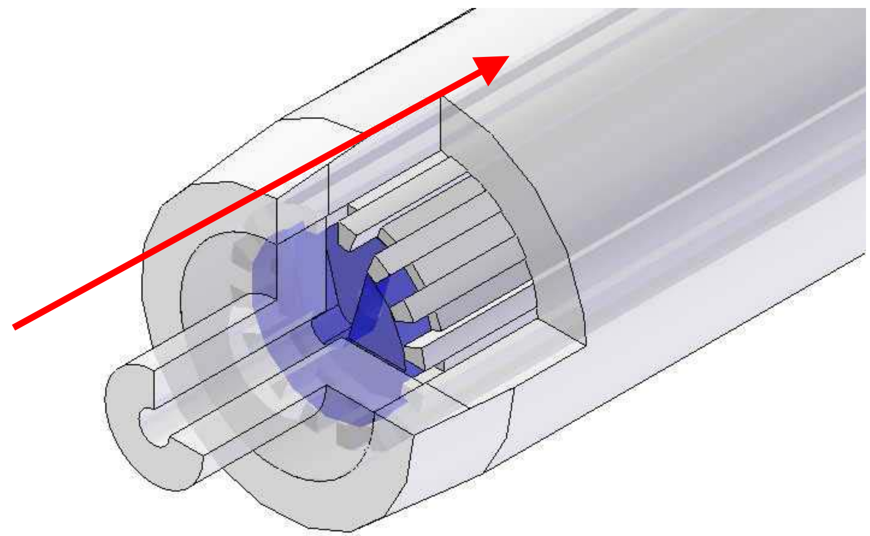
Case	Tmax °C	Deflection (um)	
Cu		Jaw edge ref	axis ref
straight	59.5	33	~100
grooved	59.5	15	~74





360° & limited arc coolant channel concepts

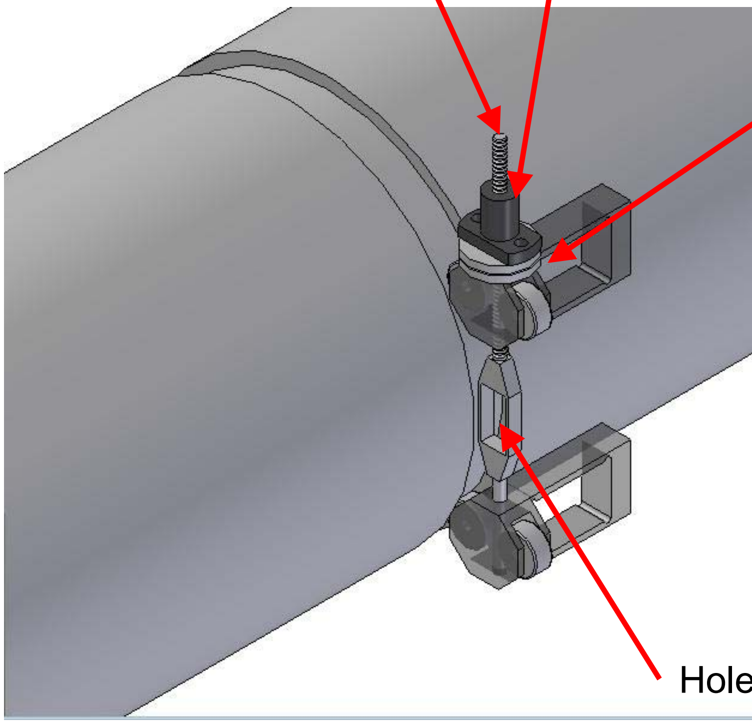


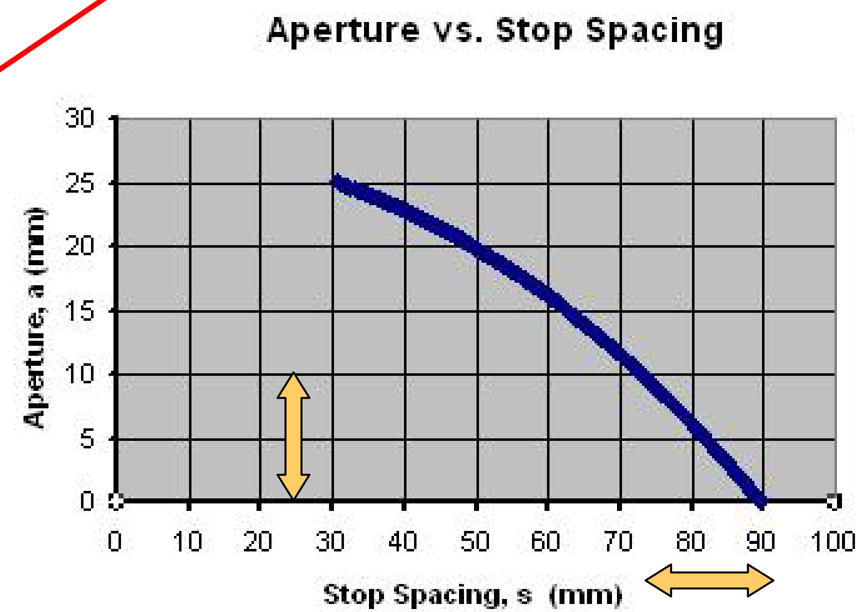


360° cooling by means of a helical channel. Lowers peak temperatures but, by cooling back side of jaw, increases net ΔT through the jaw, and therefore thermal distortion. Could use axial channels.

Limited cooling arc: free wheeling distributor – orientation controlled by gravity – directs flow to beam-side axial channels regardless of jaw angular orientation. Far side not cooled, reducing ΔT and thermal distortion.

Stop Roller Details



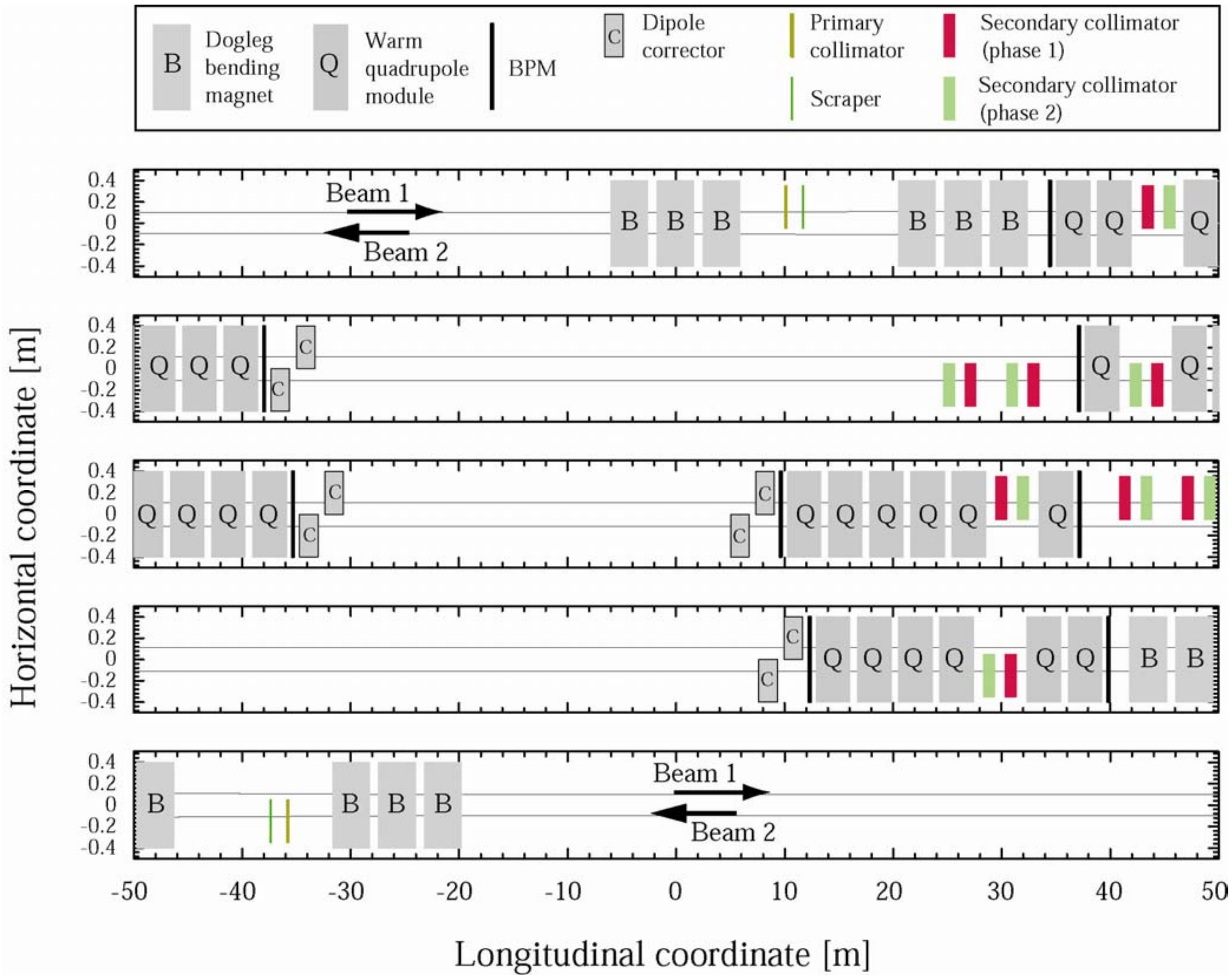


As shown in current model: aperture range limited to ~ 10mm. This can be improved but this mechanism will not be able to produce the full 60mm aperture. Auxiliary jaw retracting mechanism needed. Also note possible vulnerability of mechanism to beam-induced heating.

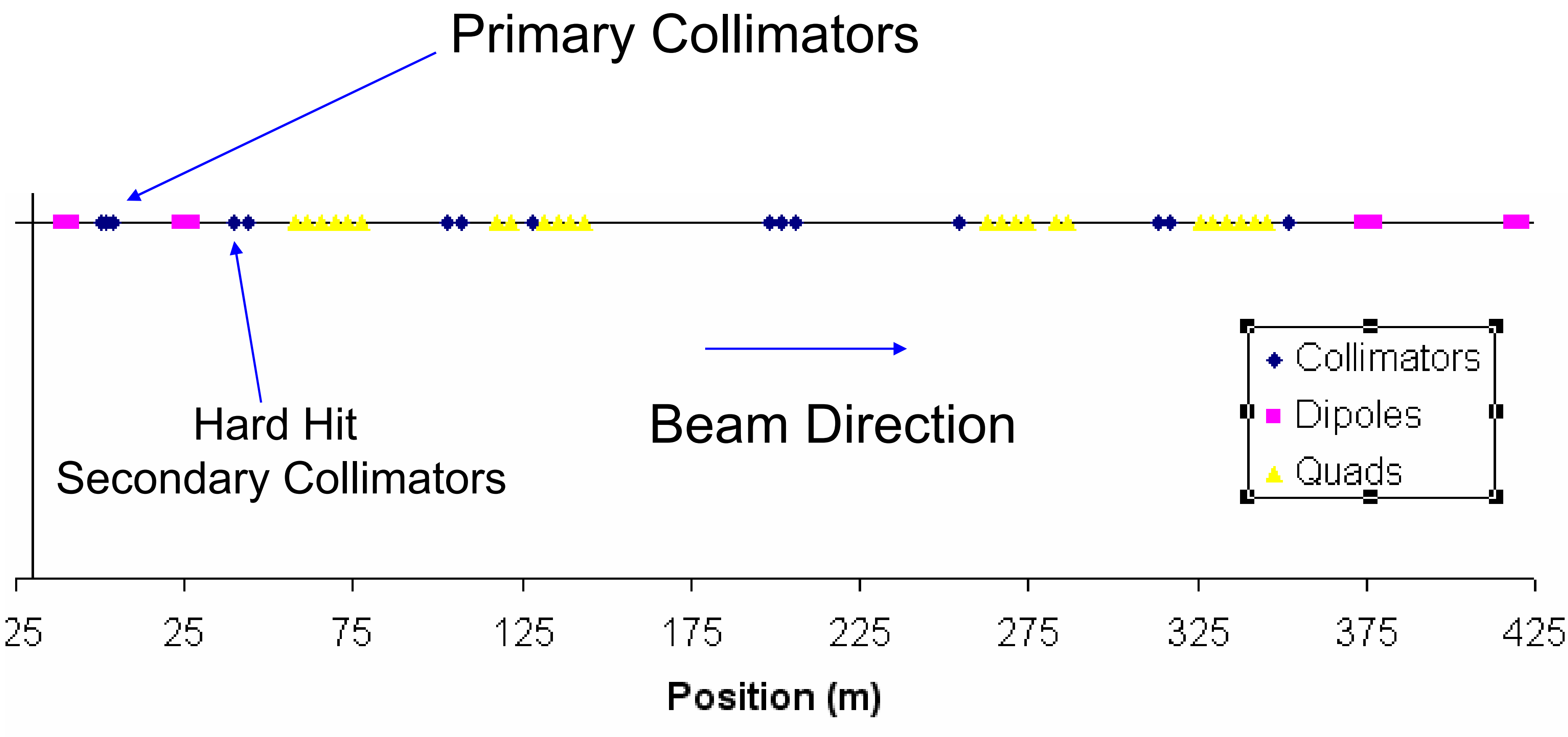
Technical Discussions of Phase I Project

- Only low Z, Be compounds, absorb sufficiently little energy, conduct the heat away fast enough, and are stiff enough to come close to meeting jaw straightness tolerance of 25um
- Deflection of jaw away from beam of collimators immediately downstream of primaries (hardest hit) may be allowed if sufficiently low and overall collimation efficiency maintained by remaining collimators
- Be, C, and Al do not provide adequate cleaning efficiency
- Shorter 50cm collimators not excluded (at least in hard hit location)
- Space constraints must be maintained
  - Beam pipe diameter must remain at 88mm
  - 60mm maximum jaw gap with 5mm center variation
- Central stop roller jaw adjust mechanism seems incompatible with 60mm gap, plus need to understand impact of having device in beam median plane
- Relatively simply geometry used to date in energy deposition studies (at SLAC) must be improved to true maximum heat load is understood
- Tests/simulations to estimate extent of damage in asy. beam abort should continue

IR3 Collimator Layout



IR7 Collimator Layout



Quench Protection Sets Maximum Current Given Collimator System Inefficiency

12min

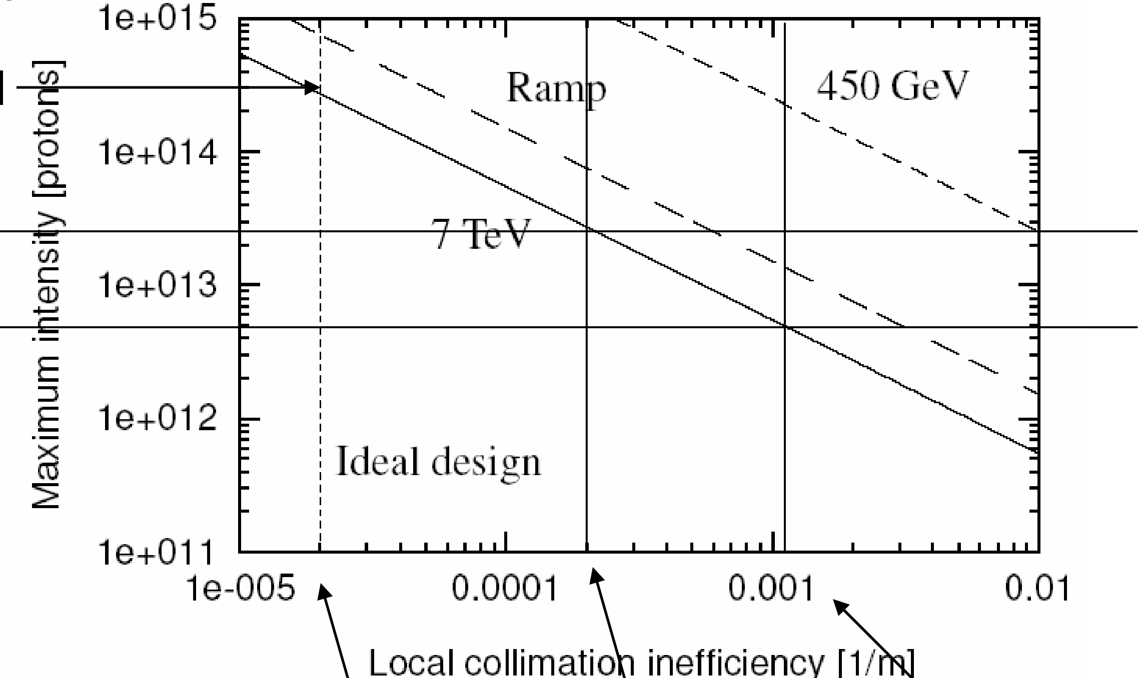
7.6E6 p/m/s @ 7 TeV

$$N^{q}_{\text{tot}} = \frac{\tau_{\min} \cdot R_q}{\tilde{\eta}_c}$$

Intensity

Inefficiency

Nom. I



2E-5 Desired

2E-4 Phase II (assumes 1m Cu)

11E-4 Phase I

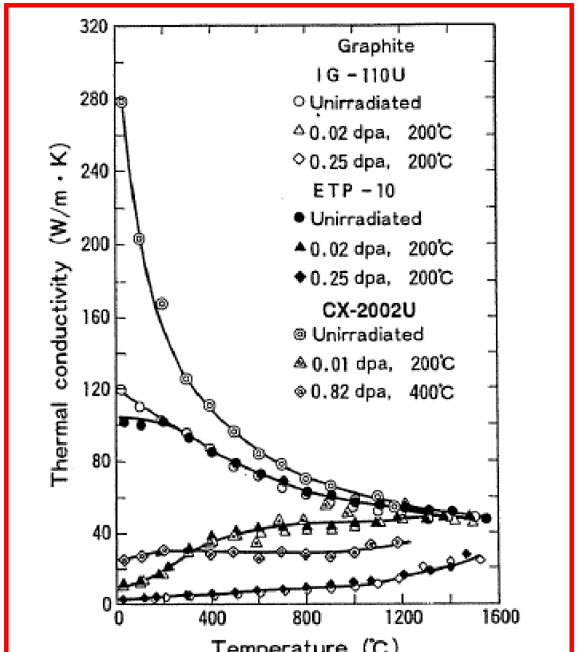
4E11 p/s x 2E-5 = 8E6 p/s corresponds to stated quench limit in Q3 given maximum dQ/dV

Why?
Key Material Properties Can Change Drastically with Irradiation

Note the x10-30 Change in Thermal Conductivity in certain types of graphite and CC composites after minimal exposure

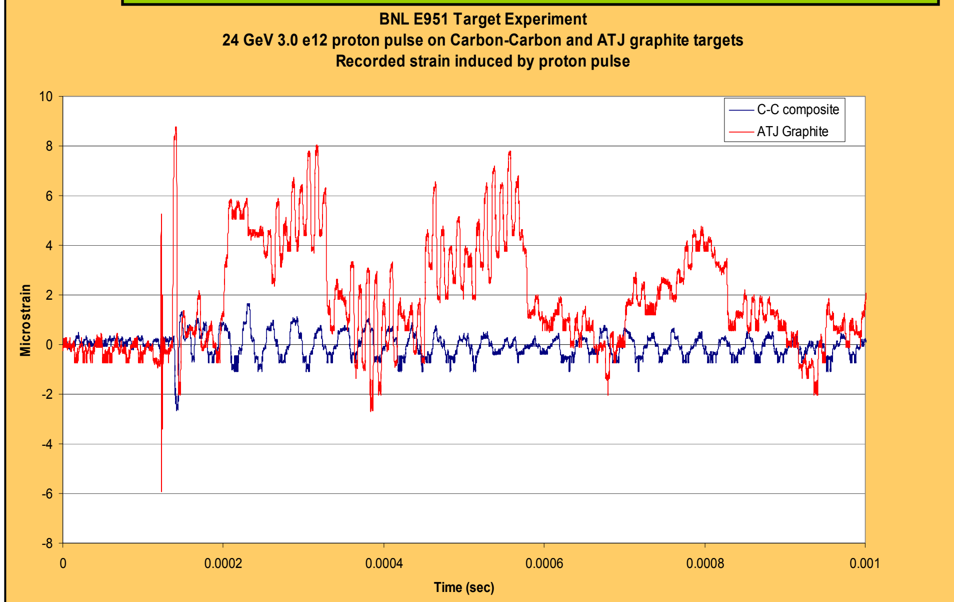
Thermal conductivity and dimensional change of neutron-irradiated graphites IG-110U, ETP-10 and GC-30

Irradiation	Thermal conductivity (W/(m K))			Dimensional change (%)		
	IG-110U	ETP-10	GC-30	IG-110U	ETP-10	GC-30
Unirradiated	119	101	16	–	–	–
0.02 dpa, 200°C	10.9	11.8	3.7	0.04	0.10	−0.14
0.25 dpa, 200°C	2.6	3.4	1.9	0.14	0.24	−0.68



Thermal conductivity of neutron-irradiated graphites.

Shock Absorption comparison between CC and graphite shown in recorded target strain (BNL E951, Muon Collider)

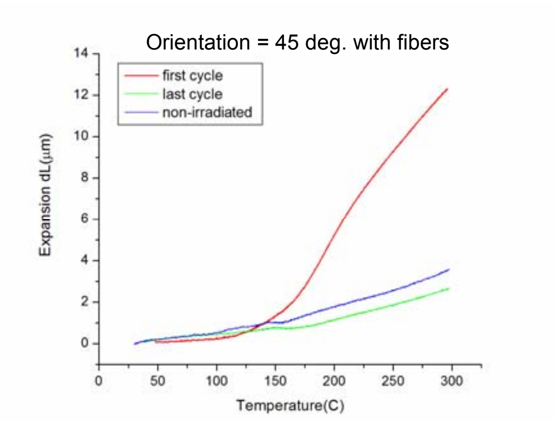


Study of Phase I Collimator Materials

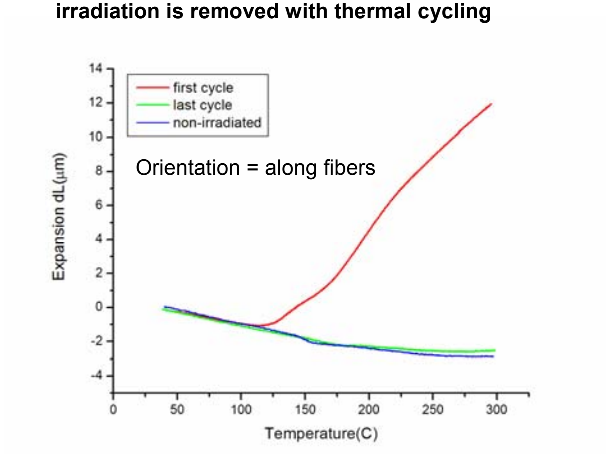
LARP

3D-weaved carbon-carbon composite
Under post-irradiation testing at BNL

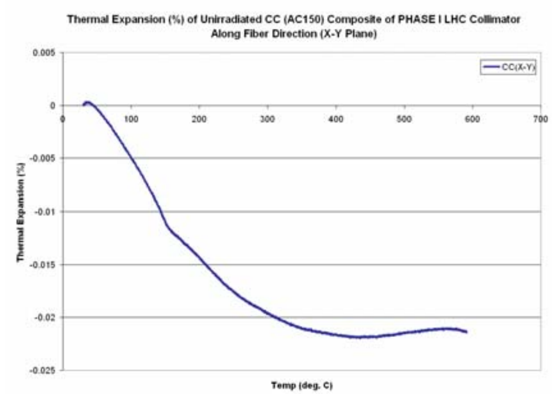
(This particular CC is evaluated for use as target in the BNL Neutrino SuperBeam)

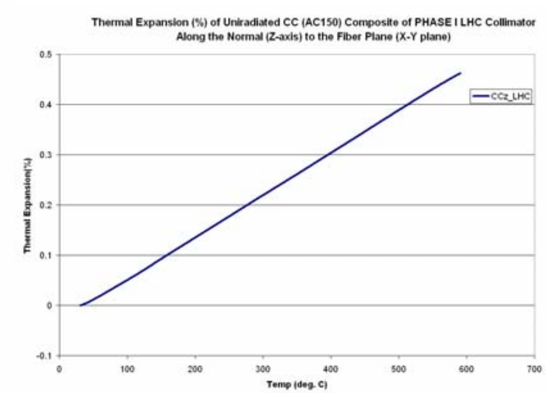


Important Results on the 3D CC composite: Damage (voids in structure) induced by irradiation is removed with thermal cycling



Experimental Study of 2D-weaved, fine structured CC composite of LHC Phase I





Preliminary results of the on-going study on PHASE I LHC Collimator materials. Results shown are for the un-irradiated samples of the actual CC composite.

Note, as in 3D CC, that composite shrinks with increased temperature along fiber direction

Proton irradiation in progress (as of April 29, 2005 and will continue until the end of the 2005 RHIC run).

Exploration of Potential Phase II Materials

Expand on-going BNL studies on new alloys & “smart” materials

Materials Currently under Testing:

Super-Invar
Inconel-718
Toyota Gum metal
AlBeMet
Beryllium
Vascomax
Ti-6Al-4V
Graphite

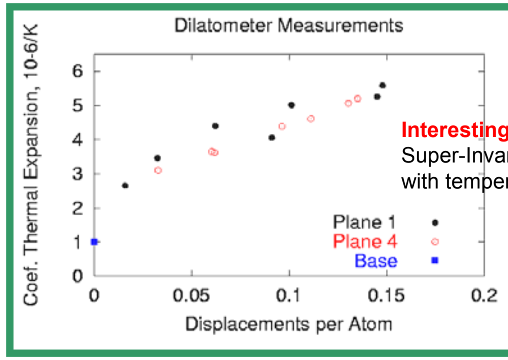
Other Materials Related to PHASE II

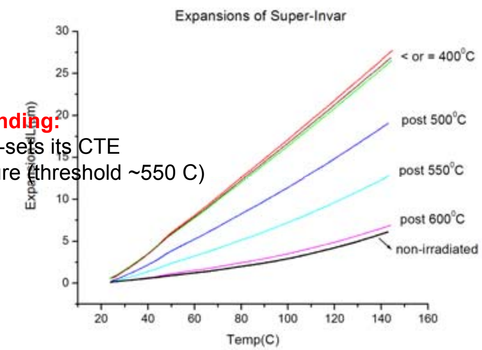
Copper

Enhanced Test Matrix for PHASE II

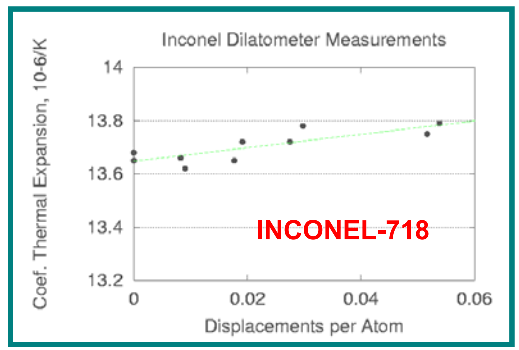
Conductivity
Resistivity (impedance-related)

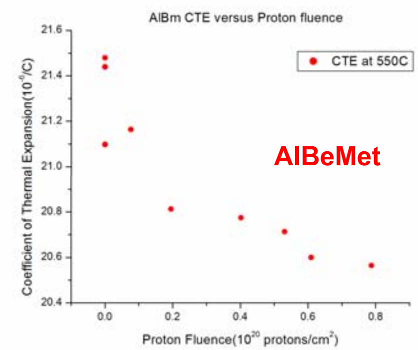
Super-INVAR

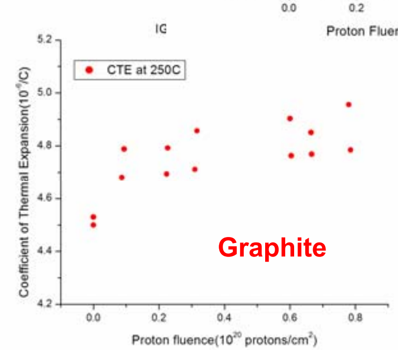




Interesting Finding:
Super-Invar re-sets its CTE
with temperature (threshold ~550 C)







LARP

FY06 Budget Planning Detail

By Task

Task	Version	LAB	Budgeted Total	Requested Labor	Requested M&S	Requested Shop	Requested Total
1	Now	FNAL	$20,000	$25,000			$25,000
		SLAC	$700,000	$390,000	$127,000	$163,000	$680,000
	Now Total		$720,000	$415,000	$127,000	$163,000	$705,000
1 Total			$720,000	$415,000	$127,000	$163,000	$705,000
2	Now	BNL	$50,000	$50,000	$5,000		$55,000
	Now Total		$50,000	$50,000	$5,000		$55,000
2 Total			$50,000	$50,000	$5,000		$55,000
3	Now	FNAL	$30,000	$50,000			$50,000
	Now Total		$30,000	$50,000			$50,000
3 Total			$30,000	$50,000			$50,000
4	Now	BNL	$50,000		$86,000		$86,000
		FNAL	$0				
	Now Total		$50,000		$86,000		$86,000
4 Total			$50,000		$86,000		$86,000
			$850,000	$515,000	$218,000	$163,000	$896,000
			$850,000	$515,000	$218,000	$163,000	$896,000